PREDICTING EVACUATION TIME

FROM

LECTURE THEATRE TYPE ROOMS

A thesis

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By

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Supervised by

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Abstract

The purpose of this research is to investigate the relationships between the movement time, travel speed and occupant density during trial evacuations, particularly for theatre-type rooms. The study mainly focuses on crowd movement behaviour within a restricted space and covers aspects of human behaviour and issues needed to be considered in terms of the characteristics of lecture theatres.

A set of experiments were carried out in three building blocks at the University of Canterbury in order to obtain the actual data for analysis. The number of students evacuating from each exit and the evacuation time were recorded, and their movement behaviour was monitored by video camera. Based on the experimental data, a numerical analysis was undertaken to formulate an equation for the prediction of evacuation time applying to lecture theatres. The developed equation was compared with other available relationships from the literature.

An evacuation model under development, named EvacuatioNZ, was applied to simulate the experiments and the results were compared with the experimental data.

The comparison showed that the developed equation showed a better performance in predicting evacuation time of lecture theatres than other available methods however, had some limitations. The EvauctioNZ model was able to be improved by using an alternative geometry input but was still not as accurate as the developed method. A recommended modification of the model was presented for improvement.

Table of Contents

List of Figures

List of Tables

1 Introduction

An evacuation model called EvacuatioNZ is currently under development at the University of Canterbury. It incorporates the Monte Carlo approach to produce probability distributions of evacuation time using a coarse network approach. As this is a node-based model, each component of a building is described as a single node. Recently, a systematic validation has been done on flow mechanics and human behavioural aspects by Teo, 2001 and Ko, 2003. However, with this model, it is difficult to simulate evacuation in a large complex space like lecture theatres.

In order to extend the application of the EvacuatioNZ to a wide range of buildings, the relationship of crowd movement, particularly in lecture theatres, is to be investigated.

A series of experiments were carried out during a semi-annual evacuation drill at the University of Canterbury. Eight lecture theatres were chosen in three different building blocks. The data collected from the experiments was processed to obtain a new relationship between occupant density and travel speed. Three sets of experimental data were also extracted from other studies for comparison purposes.

1.1 Objectives of this research

The objective of this research is to find the relationships between the movement time, occupant density and travel speed for theatre-type of rooms and formulate an equation as a result. Several tasks are performed throughout the research.

- To carry out a set of experiments during the evacuation drill in the University of Canterbury to obtain actual experimental data.

- To carry out numerical analysis based on the experimental data.

- To conclude a new relationship of crowd movement, particularly for theatre type rooms.

- To compare the prediction of the new relationship with results from other studies.

- To simulate the experiments using EvacuatioNZ and compare the results with the predictions from the new method.

1.2 Outline of this research

This report focuses on the characteristics of crowd movement in a space restricted by rows of seats. A detailed description of experimental set up is presented. The experiment is discussed from various perspectives.

Chapter 2 presents a brief background of the application of evacuation time from a design point of view as well as the data collection for the evacuation model. In terms of building characteristics, some distinctive features of lecture theatres are also addressed.

In Chapter 3, the latest findings from other literatures related to evacuation or crowd movement are summarized. Current available evacuation models are introduced including EvacuatioNZ, which is used to model the evacuation drills in this study.

In Chapter 4, the report gives a detailed description of the experiments such as building features and occupant characteristics. The collected data is attached as an Appendix for a reference.

In Chapter 5, analysis, based on the observation of videotapes is conducted, and issues from the evacuation drills are addressed.

In Chapter 6, an approach to achieve the new relationship is presented and the result is presented in the form of an equation for calculation. Three sets of data from other evacuation practices in theatres are introduced and compared with the prediction from the new method. Comparison with other available relationships of crowd movement is also made.

In Chapter 7, the experiment is modelled by EvacuatioNZ. Two scenarios are considered in terms of different geometrical inputs. The results are compared with the experimental data, as well as the prediction from the new method.

Chapter 8 gives a summary of the conclusions of this study and some further work is suggested.

2 Background

Safety issues are of increasing concern to society. The need to safely evacuate people from buildings, particularly during fire incidents, continues to be an essential requirement. From an engineering design perspective, performance-based solutions are becoming more popular accommodating the growing complexity of structures. To achieve the purpose of design and safeguard people's life from fire, an approach to compare two distinctive times, ASET (Available Safe Egress Time) and RSET (Required Safe Egress Time), is well developed. Usually, RSET considers the human factors related to evacuation and compares with the time taken for fire condition to become untenable within a building. The problem to be addressed is that little knowledge is available as to how the human individual responds to various environments. It is therefore helpful to supply the knowledge related to psychological aspects for fire engineers to conduct research in the area of human factors.

Evacuation time, normally referred as REST, is divided into several elements considering different issues throughout the evacuation process. In the Fire Engineering Design Guide, (Buchanan, 2001) an expression formed with six elemental times is given as:

$$t_{ev} = t_d + t_a + t_o + t_i + t_t + t_q$$ **Equation 2.1**

Where:

t_d is the time from fire start until detection of the fire

t_a is the time from detection until the alarm system activates

t_o is the time from alarm arising until the time occupants make a decision to respond

t_i is the time for occupants to investigate the fire and collect belongings

t_t is the travel time to a place of safety

t_q is the queuing time at doorways or other congestion point

Usually, term t_o and t_i are combined together and recognized as the pre-movement time or pre-evacuation time (t_{pre}). This period of time is extremely difficult to be described in a quantitative way due to the uncertainty of human behaviour. In this research, the main subject, quoted as t_{move}, consists of two parts, the travel time through egress route (t_t) and the queuing time along passageway (t_q). It is one of the most important elements in the evacuation time, particularly in the buildings where potentially a large number of people are presented, such as lecture theatres or stadiums.

2.1 Data Collection for evacuation models

With increasingly complex building designs, it becomes difficult to assess the evacuation process within a complicated geometric network by means of hand calculation. Due to the development of computation technology, computer model simulation becomes a popular implementation and makes a significant contribution to design work. All of these evacuation models rely on experimental data, either in their developments, which apply calculation methods based on observations, or as an input. It is important to understand the available experimental data which can be used for calibration and validation. In order to extend our knowledge of human behaviour in fire, better data collection is necessary for the development of the equations or algorithms applied in the models or to be an input. Also, data is needed for verification or validation of the models.

Basically, all evacuation models require general data on, for example:

- Delay times for decision making
- Walking speed on various types of surfaces such as stairs
- Occupant characteristics including age, gender, degree of training, familiarity and so on
- Effects of obstructions along travel paths
- Exit choice decisions

Generally, there are four available methods to collect required data.

Videotape observation

This is the most popular method to achieve the experiment goal and considered an ideal as it shows exactly how people behave in crowd streams. The number of people using each exit and elapsed time is recorded on the tape and the characteristics of occupants can be determined from the footage. Another advantage is that video can be replayed. This repeatable process is significantly advantageous on analysis of behavioural aspect. However, the videotape rarely captures an actual fire incident. When people are exposed to a stressful situation, they behave differently from what they do in a normal evacuation drill (Fahy, 2002). Thus, results from video observation analysis have their limitations.

Laboratory experiment

This method refers to the test on the effects of smoke on decision-making and travel speed (Jin, 1997). Researchers could not carry out such experiments due to ethical issues and restrictions on the use of human subjects. However, some research on people's movement behaviour can be achieved through small-scale experiments in laboratory (Helbing, et al. 2005).

Manual Counting

This method is simple and effective when relevant equipment is not available. The data is collected by testers, manually or using data-loggers, which records a corresponding time at each instance a number is input. It is easy to organize with this method and the test position is flexible to meet the experiment requirement.

Survey and interview

This method has been used for many years to obtain information from survivors of actual fire incidents. Although it gives real-life evidence and detailed reports of elapsed times, the recollections and description from survivors are subjective, and some details might be omitted or overstated.

However, there are some barriers to the improvement of data collection and application. Much of data collected over the past years has not been published or has not given a full description of experiment set up or building features. Some data was not shared as the research was funded by companies that claim a propriety right to the data. A standard data reporting system is desired to achieve data comparison through various sources.

2.2 Characteristics of Lecture theatre

Lecture theatres, usually described as a large size space in buildings with potentially a high occupant load, always draw more attention to fire engineers while they are carrying out safety design. Due to its distinctive features, significant care needs to be taken in predicting evacuation times for this type of room.

From the traditional fire safety design, the number of exits is specified based on the occupant load while each exit is considered to be used efficiently with nominal flow rate during evacuations. When a lecture theatre design is presented, more attention to environmental and human behavioural factors such as occupant distribution, knowledge of the building and familiarity with the exit, should be considered. Also to be considered is how people’s decision making determines how exit systems will be used in a large-size, complex-geometry building.

The movement within a lecture theatre can be described as simultaneous mergers of a number of flows into a passageway of restricted length. Flows from each row merge into the main stream in the aisle leading to the exit. For long passageways connected with long seat rows, once the density in the passageway area reaches a certain level, the movement of people from rows slows down, and often completely stops (Predtechenskii and Milinskii, 1978). Particularly for lecture theatre rooms, there are a number of parameters which may impact on this complicated process:

- ❖ The exit system in the theatre (aisle on one side or both sides)
- ❖ The form of the passageway (flat or inclined)
- ❖ The number of seats in each row
- ❖ The number of rows leading to the passageway
- ❖ The width of the row
- ❖ The width of the passageway

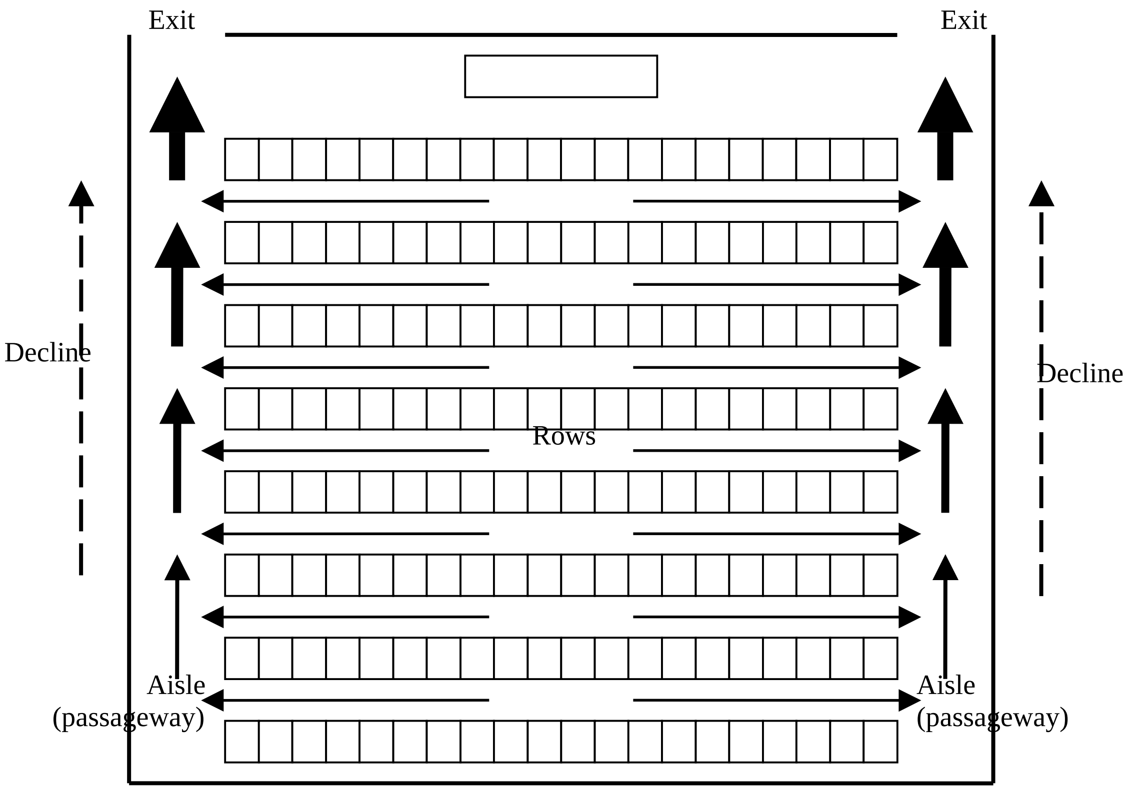


Figure 2.1: Sketch of crowd movement in lecture room

Most frequently, the lecture theatres are located in educational buildings such as schools of middle and higher educational institutions. Normally, high occupant load is presented in this type of building during the day where classes are running in most of the classrooms or lecture theatres. Between classes, intensive flows transfer among different locations. Thus, crowd movement is of more concern if people are exposed to a fire incident in this type of building. The *Life Safety Code 101*(NPFA, 2001) states:

14.7.1.2

Emergency egress and relocation drills shall be conducted as fallow:

1. *Not less than one emergency egress and relocation drill shall be conducted every month.*
2. *All occupants of the building shall participate in the drill.*
3. *One additional emergency egress and relocation drill, other than for educational occupancies that are open on a year-round basis, shall be required within the first 30 days of operation.*

14.7.1.3

All emergency and relocation drill alarms shall be sounded on the fire alarm system.

Another type of building where projection theatres are often contained is the entertainment complex. Normally, a large auditorium area designed to accommodate audiences of thousands has to be designed wisely to provide sufficient evacuation capacity in an emergency. In terms of activities at different periods of time, there are four types of movement in this type of building:

- ❖ Entering the building before the start of events
- ❖ Movement during intervals
- ❖ Evacuation from the building at the end of events
- ❖ Evacuation under an emergency situation

In the *Life Safety Code 101*, this type of building is categorized as assembly occupancy with the requirement of evacuation drill as:

A.12.7.6

It is important that an adequate number of competent attendants are on duty at all times when the assembly occupancy is occupied.

12.7.6.1

The employees or attendants of assembly occupancies shall be trained and drilled in the duties they are to perform in case of fire, panic, or other emergency to effect orderly exiting.

12.7.6.2

Employees or attendants of assembly occupancies shall be instructed in the proper use of portable fire extinguishers and other manual fire suppression equipment where provided.

12.7.6.3

In theatres, motion picture theatres, auditoriums, and other similar assembly occupancies with occupant loads exceeding 300 where there are noncontinuous programs, an audible announcement shall be made, or a projected image shall be shown, prior to the start of each program to notify occupants of the location of the exits to be used in case of a fire or other emergency.

Since evacuation plays an extraordinarily significant role in fire safety design, particularly for lecture theatres, more study on crowd movement in this type of room is required and thus this is the subject of this research.

3 Literature Review

3.1 Crowd movement

In terms of fire safety design, the industry is moving towards a performance-based approach based on performance criteria. A fundamental objective in performance-based fire safety design is to safeguard the life of occupants in a building during a fire. Thus, the RSET becomes significant during the design process. Previously, this required safe egress time is achieved by hand calculation method giving a general estimation of how fast a crowd group passes through a congestion point. Predominantly, the equations given in the Emergency Movement Chapter of SFPE handbook (Nelson and Mowrer, 2002) is well applied to calculate people flow rate. Several methods developed or being developed by other researchers are also available. These relationships are derived from either experimental data or information from other literature for various situations. As each method is developed from a different data source, which varies due to the uncertainty of human behaviour, some applications are limited as each case is unique. Regarding the prediction of evacuation time for lecture theatres, a comparison of different methods is done and discussed in a latter chapter.

Fruin (1976)

Among the early studies, Fruin's book, *Pedestrian Planning and Design*, was a well known study on crowd movement. His work is often referred to in dynamic exit analysis. In the book, the Level-of Service Concept was first developed in the field of traffic engineering. Based on the walking speed, pedestrian spacing and the probabilities of conflict in various flows, there are six levels of crowd people for walkways and stairs. However, it was doubted that the data used for level-of-service E and F was improperly used (Pauls, 1987). From the experimental data collected, it shows that travel speeds for crowd flows is strongly affected by occupant density once it reaches about 0.43 persons/m^2. Figure 3.1 shows the effect of increased traffic density.

Figure 3.1: Pedestrian speed on walkways (From Fruin 1976, Figure 3.2)

Predtechenskii & Milinskii (1978)

Predtechenskii and Milimskii carried out a wide range of experiments earlier. The visual observation was also made by standing to one side or participating in the flow. Photography was also applied to record the image of a characteristic segment of flow path. A great number of traffic flows were measured in different situation including 363 measurements of the travel speed upward in stairwells. (See Figure 3.2)

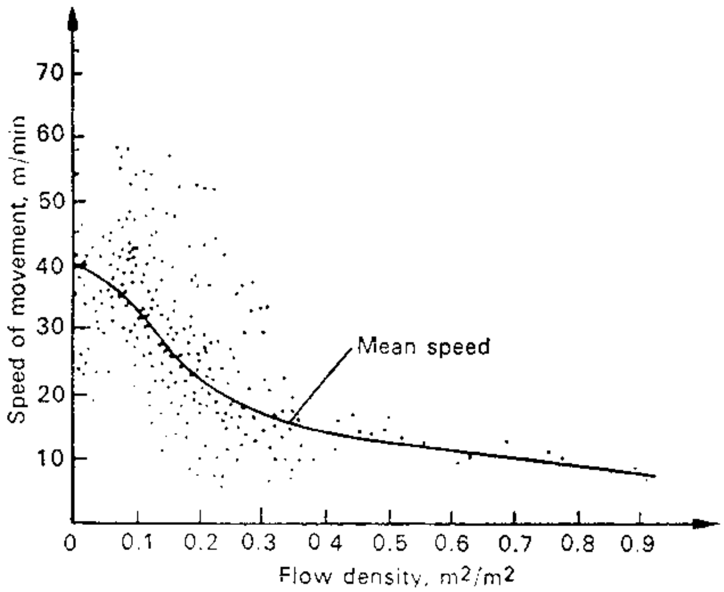


Figure 3.2: Movement speed of pedestrian crowd climbing staircases. (From Predtechenskii & Milinskii , 1978 Figure 15)

Mean values of speeds in various public buildings were suggested based on the measurement. In theatres and educational buildings, travel speed varies from 15 ~ 20 m/min. In industrial buildings, the range is between 25 ~ 30 m/min. For movement on stairs, the most probable speeds are 20 ~ 25 m/min. In order to describe the relationship between speed and density, an empirical equation was given on the basis of thousands of measurements of the movement around doorway.

$$v = 112D^4 - 380D^3 + 343D^2 - 217D + 57m/\min$$

This equation is suitable for the interval of densities from 0 to 0.92 m^2/ m^2, which is the ratio of the sum of horizontal projection of people to the floor area occupied by the flow. For different forms of path, a coefficient 'm_0' is introduced, expressed as:

For movement through doorways:

$$m_0 = 1.17 + 0.13\sin(6.03D - 0.12)$$

For movement along stairs downwards:

$$m_0 = 0.775 + 0.44e^{-0.39D}\sin(0.56D - 0.224)$$

Thus,

$$v' = m_0 v_0$$

Taking the state of people into account, a coefficient of conditions of moment, quoted 'μ', is also defined to estimate the speed variation under emergent situation. For normal condition, this coefficient is 1. Under emergency conditions, for horizontal paths and doorways, μ varies according to a linear relation:

$$\mu_e = 1.49 - 0.36D$$

Thus,

$$v' = m_0 v_0 \mu_e$$

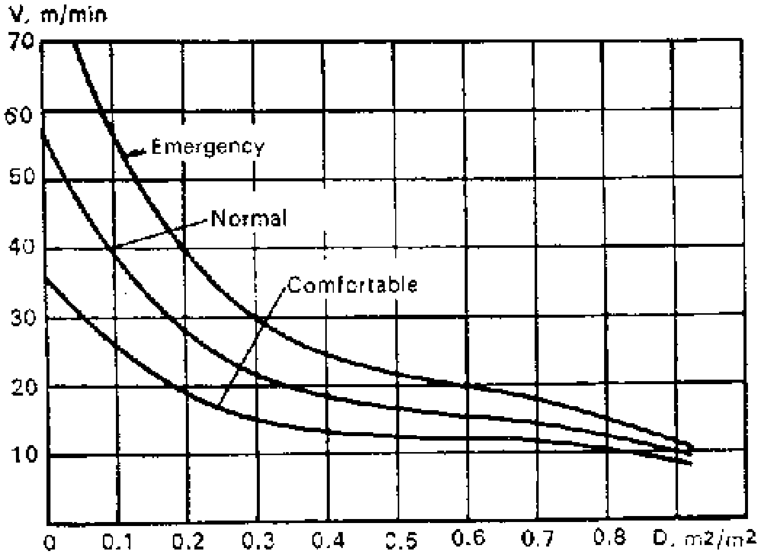


Figure 3.3: Movement speed along horizontal paths in different conditions (From Predtechenskii & Milinskii , 1978 Figure 15)

Particularly for a lecture theatre type room, an alternative method to specify the duration of the evacuation was developed, which divided the process into three successive periods: the time for people to emerge from rows into the main stream in aisle; the time for the movement of stream from back to front; the remaining time of the movement of the trailing part of the stream. Based on the assumptions that the main passageway is horizontal and the width of the row is 1m, an empirical formula is recommended as:

$$t = \varphi \frac{mn}{\delta\gamma} \min$$

Where

φ is a coefficient accounting for the size of horizontal projection of the majority of population.

γ is a coefficient in m/min accounting for the flow density in the zone of stabilization.

m is the number of rows;

n is the number of seats in each row.

The detailed information about this method can be found in "*Planning for Foot Traffic Flow in Buildings*" (Predtechenskii & Milinskii , 1978). This method requires detailed information about the layout of the auditorium area, which is usually difficult to obtain at design stage.

Holmberg (1997)

A relationship, giving the maximum flow rate through a door of specified width, was developed by Holmberg based on a series of experiments carried out at the University of Lund. These experiments were conducted within the engineering departments building using a group of students as test subjects aged between 20 to 30 years old. They were asked to walk through an experimental set-up area in various densities. The information of velocity versus inter-person distance was achieved by a video image analysis technique developed by Thompson. (See Figure 3.4) The relationship was derived from the experimental data as the best-fit line shown as below:

$$Q = 0.0026 \times w - 0.59$$

Where

Q = flow rate (persons/second)

w = door width (mm)

It was noted that the flow rate in the equation was the maximum flow rate for the period of experiment time and this result seems to be larger than the flow rates from other research.

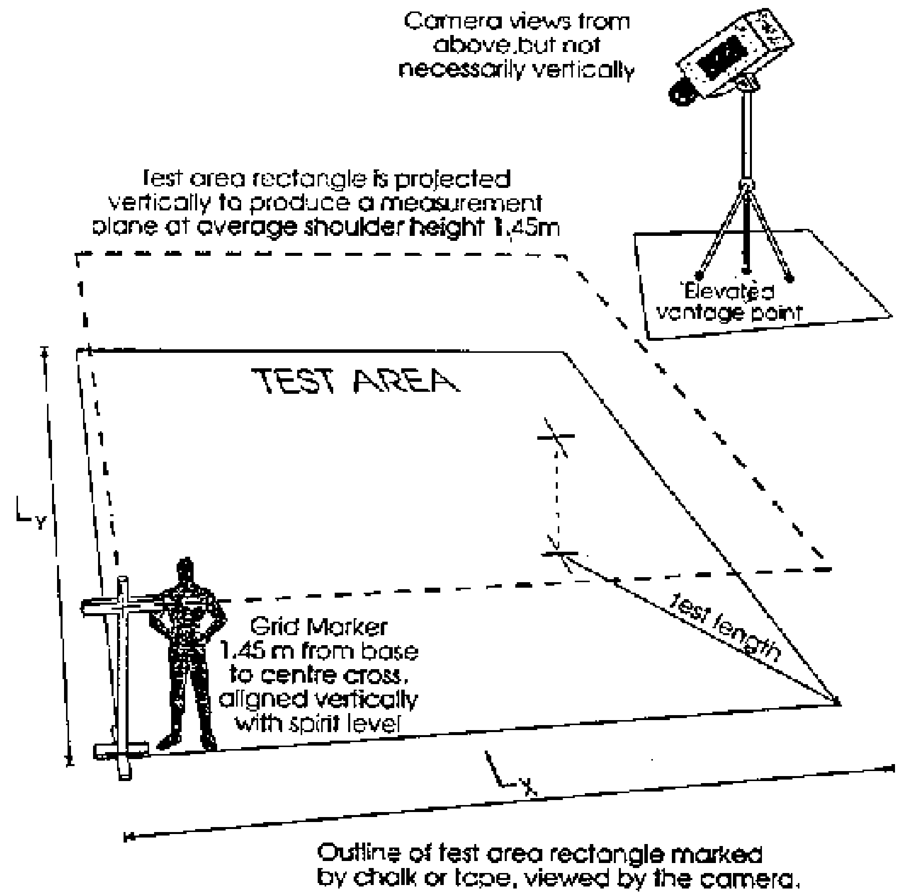


Figure 3.4: Test area and the perspective plane for a horizontal test position. A vertical marker I used to identity the corners of the perspective plane. (Thompson, 1994)

Nelson & MacLennan (Nelson, 2002)

A well-incorporated method to calculate evacuation time is presented in the SFPE handbook. It states that travel speed varies depending on the flow density in the range between 0.54 to 3.8 persons / m^2. Within this range, the relationship between speed of travel S (m/s) and density of occupants D (ppl/m^2) is expressed as:

$$S = k - akD$$

In the equation, factor ‘a’ is a constant for different unit system. ‘k’ is another factor that varies with different exit route element. Table 3.1 is extracted from the SFPE handbook giving the concrete values for k factor and the corresponding unimpeded speed.

Table 3.1: Constants of k (Extract from SFPE handbook Table 3-14.2 & 3-14.4)

Exit Route Element		k	Unimpeded speed (m/s)
Corridor, Aisle, Ramp, Doorway		1.40	1.19
Stairs			
Riser (mm)	Tread (mm)		
191	254	1.00	0.85
178	280	1.08	0.95
165	305	1.16	1.00
165	330	1.23	1.05

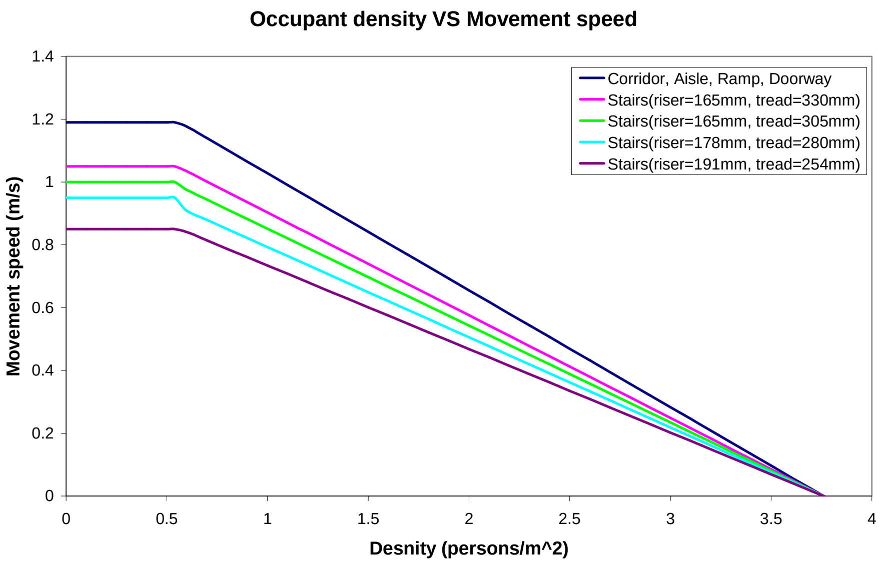


Figure 3.5: Evacuation speed as a function of density (From SFPE handbook Figure 3-14.4)

To estimate the movement of crowd population through a congestion point, the flow rate can be expressed as:

$$F = (1 - aD)kDW_e$$

According to the form of this equation, two variables, occupant density and effective width affect the flow rate. Removing the effective width, the specific flow, persons per unit of time per unit of area, has a polynomial relationship with occupant density. The specific flow reaches its maximum value at the point where occupant density is around 1.9 persons / m^2. The relationship from this method is well applied in fire engineering designs but it may not be appropriate for some special cases such as lecture theatres.

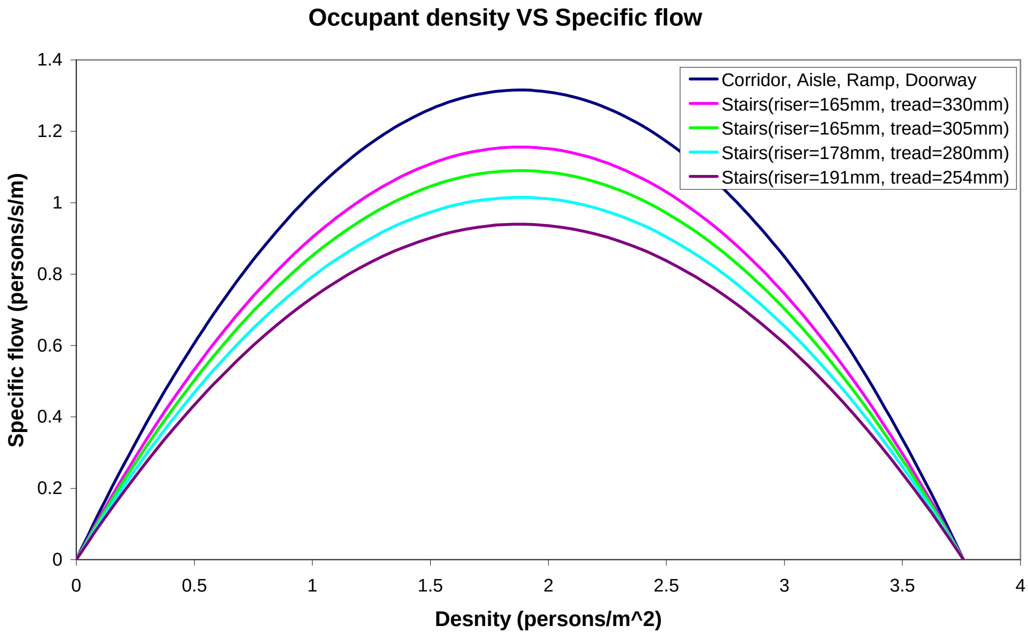


Figure 3.6: Specific flow as a function of density. (From SFPE handbook Figure 3-14.5)

For various research purposes, a number of studies were conducted looking at different crowd population in different situations. A summary of studies related to crowd movement are in these extracts from Hoskin, 2004.

Table 3.2: Previous crowd flow studies (From Hoskin, 2004, Table 2)

Study Author	Crowd Type	Terrain	Study Type	Density at max flow rate (ppl/m^2)	Max flow rate (ppl/s/m)
Ando et al (1988)	Rail commuters	Flat	Speed-age relationship	-	-
Fruin (1971)	Walkways	Flat	Speed-density relationship	2.04	1.37
	Stairs	Stairs		2.78	0.93
Nelson & MacLennan	Evacuation trials	-	Safe egress times	-	-
Pauls	Evacuations	Stairs	Speed-density relationship	2.04	0.92
Poyner, et al (1972)	Football crowd	Flat	Speed-density relationship	-	1.96
Predtechenskii (1969)	Stadium	Flat	Speed-density relationship	4.00	0.80
		Stairs		2.04	0.66
Proulx (2001)	Video footage	-	Human behaviour	-	-
Puskarev (1975)	Shopping malls & Sidewalks	Flat	Collision avoidance	1.0	0.98
Tanaboriboon et al (1989)	Market places	Flat	Levels of service	2.7	1.68

- : is not specified in the original source.

3.2 Current evacuation models

Nowadays, except for hand calculation, engineers apply evacuation models to carry out the analysis of fire safety in buildings, in order to achieve a more realistic evacuation calculation.

Currently, there are two different ways to model people's movement within buildings. In terms of movement, a type of model, called the engineering, physical science or "ball-bearing" model, is well used for analysis of escape behaviour in the Fire Engineering Industry. The model of human reactions is complemented by the assumption that in the extreme situations, crushing occurs when panicked people, characterized by the non-social behaviour of a homogeneous crowd group, are competing for diminishing access to an exit irrationally. As a result, people's movement is able to be modelled as non-thinking objects propelled to an exit along the egress route. In this type of model, the time for people to escape and the direction of movement is determined by the speed of fire and smoke spread, the occupants load and the dimensions of egress routes (Stollard and Johnston, 1994, Rubadiri 1996).

On the other hand, the other type of model is regarded as a “social science” or psychological model of human reactions, which treats people as “active agents” who think and act based on the available information, social factors and their role within the building, such as staff or public. This model emphasizes patterns of behaviour (decision making) rather than where this behaviour takes place, which is well represented in the first model. In this case, people are expected to behave rationally. As this model focuses on the information people need to act appropriately, the physical environment is sometimes poorly defined. According to the logic of this model, the time for people to escape is determined predominantly by the information available to the occupants about fire threat and building structures. Both models have their strengths and weaknesses and require validations regarding to different components (Stollard and Johnston, 1994, Rubadiri 1996).

To simulate people’s movement within an enclosure, there are a number of evacuation models to choose from. Each model has its own unique characteristics and specialties. To help the user to select the appropriate model for different situations, a comprehensive model review of 28 past and current egress models has been developed by Kuligowski, 2005. Table 3.3 is a summary of overall features for egress models. A couple of evacuation models are briefly introduced in this section.

Table 3.3: Summary of current evacuation models

Model	*Purpose*	*Available to public*	*Modeling Method*	*Grid/ Structure*	*Perspective of M/O*	*Behavior*	*Movement*	*Fire data*	*CAD*	*Visual*	*Valid*
EVACNET4	1	Y	M-O	C	G	N	UC	N	N	N	FD
Takahashi's Fluid	1	N2	M-O	C	G	N/FA	FA-D	N	N	2-D	FD
PathFinder	1	N3	M	F	I/G	N	D	N	Y	2-D	N
TIMTEX	4	Y	M	C	G/I	N	D	N	N	N	PE
WAYOUT	5	Y	M	C	G	N	D	N	N	2-D	FD
Magnetic Model	1	U	M	F	I	FA/I	FA	N	N	2-D	N
EESCAPE	5	N3	M	C	G	N	D	N	N	N	FD
EgressPro	5	N2	M	C	G	N	D	Y2	N	N	N
ENTROPY	5	U	M/PB	C	G/I	N	Ac K, FA	N	N	N	OM
STEPs	1	Y	M/PB	F	I	FA	P, E	N	Y	3-D	C
PED/PAX	3	Y/N2	PB	C	G	I	D	N	Y	2,3-D	N
EXIT89	1*	N1	PB	C	I	I/C(smk)	D	Y1	N	N	FD
Simulex	1	Y	PB	Co.	I	I	ID	N	Y	2-D	FD,PE
GridFlow	1	Y	PB	Co.	I	I	D	N	Y	2,3-D	FD, PE
ALLSAFE	5	N3	PB	C	G	I	Un F	Y1,2	N	2-D	OM
CRISP	1	N3	B-RA	F	I	R/C, P	E,D	Y3	Y	2,3-D	FD
ASERI	1	Y	B-RA	Co.	I	R/C, P	ID	Y1,2	N, F	2,3-D	FD*-
BFIRES- 2	4	N2/U	B-RA	F	I	R/C, P	UC**	Y2	N	N	N
BldEXO	1	Y	B	F	I	R/C, P	P, E	Y1,2	Y	2,3-D	FD
EGRESS 2002	1	N3	B	F	I	R/C, P	P,D	Y2	N	2-D	FD
EXITT	2	Y	B	C	I	R/C	C	Y1,2	N	2-D	N
VEgAS	1	N2/U	B	F	I	AI	ID	Y1?	Y	3-D	N
E-SCAPE	1	U	B	C	I	R/C, P	OML	Y2	N	2-D	N
BGRAF	1	N1	B	F	I	R/C, P	UC?	Y1,2	N, F	2-D?	FD
EvacSim	1	N1	B	F	I	R/C, P	D	Y2	N	N	N
Legion	1	Y	B	Co.	I	AI	D,C	Y2	Y	2,3-D	FD,OM

* Especially for high-rise building; ** User specifies; # of time frames, an occupant moves to a grid point during each time frame; *- Fire drills and sensitivity analysis on the model; ? Indicates that a category is unclear or unknown

Notation

Purpose
1: simulate any type of building
2: models that specialize in residences
3: models that specialize in public transport stations
4: models that are capable of simulating low-rise buildings (under 75 feet)
5: models that only simulate 1-route/exit of the building

Availability to the public
Y: available to the public for free or a fee
N1: model has no yet been released
N2: model is no longer in use
N3: model used for the client on a consultancy basis

Modelling method
B: behavioural models
B-RA: behavioural model with risk assessment capabilities
M: movement models
M-O: movement optimization models
PB: partial behaviour models

Grid/Structure
F: fine network
C: coarse network

Perspective of the model/occupant
G: globally
I: individually

Behaviour
N: no behaviour
I: implicit behaviour
R/C: rules o conditional behaviour
FA: function analogy
AI: artificial intelligence

Movement
D: density correlation
UC: user's choice
ID: inter-person distance
P: potential
E: emptiness of next grid cell
C: conditional
FA: functional analogy
OML: other model link
Ac K: acquiring knowledge
Un F: unimpeded flow

Fire data
Y1: importing fire data from another model
Y2: allowing users to input specific fire data at certain times
Y3: model has its own simultaneous fire model

CAD
N: not allowing for the input of CAD drawings
Y: allowing for the input of CAD drawings
F: upgrading to use CAD drawings

Visual:
2-D: 2-D visualization
3-D: 3-D visualization
N: no visualization

Validation:
C: validation against code requirements
FD: validation against fire drills or other experimental data
PE: validation against literature on past evacuation experiments
OM: validation against other model

EVACENT+ (Watts, 1987)

EVACENT+ is an interactive computer program in which a network description of buildings and occupant's attributes are specified in input files. Based on the information given, it produces an optimal description of the evacuation process in an output file, which means the evacuation time predicted by the model is the minimum time in an ideal situation. However, there is no feature associated with any behavioural aspects in the model.

EXIT89 (Meacham, 2004 and Kuligowski, 2005)

The EXIT89 program models evacuation of a large building with the ability to track the path of each occupant. It contains various input features such as shortest travel route, choice of occupant's body size, choice of group's travel speed, a random delay time and the modelling of disables' behaviours. The buildings are represented by a series of nodes and arcs in the model. The correlation between traffic speed and flow density from Predtechenskii and Miliinishii is applied in this model. The user needs to define the building geometry by himself with a network description of the structure. Population and travel density are based on body sizes specified by the user. Generally, the model does not simulate people's behaviour explicitly. But it implicitly handles the decision process to evacuation by setting a delayed time before the program begins to calculate the evacuation for a given occupant.

BuildingEXODUS (Gwynne et al, 1999)

BuildingEXODUS is an egress model designed to simulate the evacuation of a large number of occupants from a variety of enclosures. It consists of five core interacting sub-models which are the Occupant, Movement, Behaviour, Toxicity and Hazard. The interaction among sub-models is interpreted in Figure 3.7. The model uses the fine network approach in which the geometry of buildings is described by a two-dimensional spatial grid. CAD drawing is also able to be imported into this model as the building layout. In terms of individual's personal attributes, the Behaviour Sub-model determines the occupant's response to the current situation and passes its decision on the Movement Sub-model. This could give the model a potential advantage, the introduction of an adequate behavioural capability, demonstrated through enabling occupants to make decisions to select the most viable exit during the evacuation.

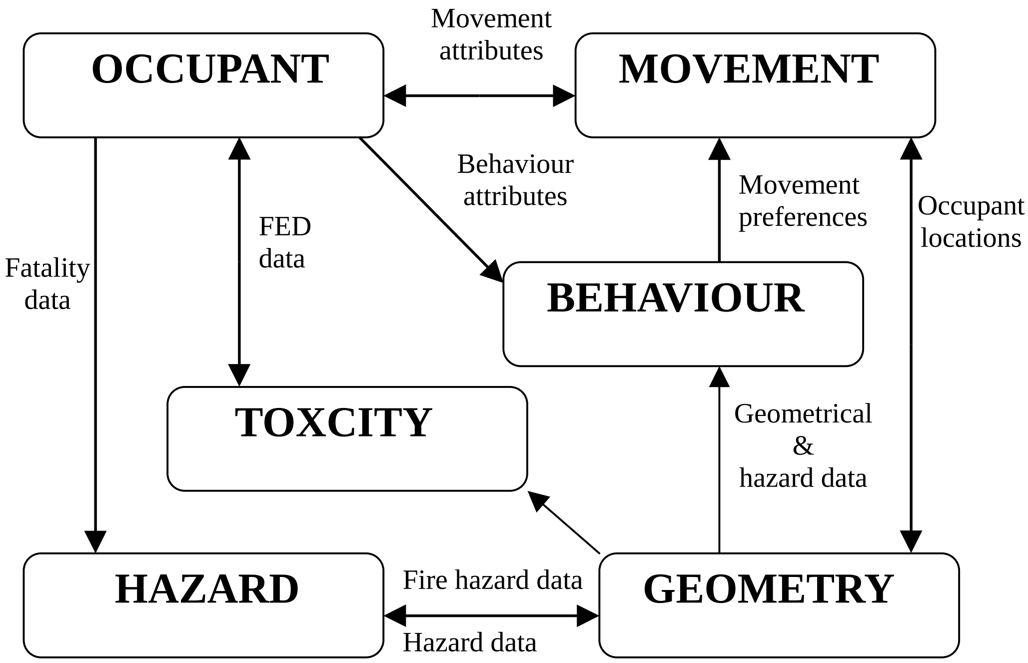


Figure 3.7: Interaction of EXODUS modules (From Figure 1, Gwynne, 1998)

To assess the performance of prediction from the model, the evacuation patterns in a lecture hall were simulated by the model. In terms of different exit choice behaviours, four scenarios were considered in the analysis. From the result, the prediction of BuildingEXODUS had relatively good agreement with experimental data (Li and Chow, 2001).

Another systematic comparison of prediction produced by the BuildingEXODUS and experimental data was carried out by Gwynne. The data set used for analysis is the Tsukuba pavilion evacuation data. Generally, the model predictions were found to match the quantitative experimental results very well. Moreover, it was able to reproduce certain qualitative observations such as the tendency of occupants' exit choosing (Gwynne, 1999).

Simulex (Kuligowski et al, 2005 and Thompson et al, 1995)

Simulex, as a sophisticated ball-bearing model, has the ability to simulate the egress of a large number of people from a geometrically complex building. The two-dimensional network of buildings is imported from CAD drawing. It allows the user to create a population combined with many different occupant types. Another technique, called 'distance mapping', is applied to assess travel distances throughout a building space. It is particularly effective on the estimation of maximum travel distances in large buildings. However, there are certain limitations during the simulations in which occupants sometimes get 'stuck' at a transition point where it connects with different levels. This can be fixed by slight adjustment of link position. A comparison of evacuation results from Simulex and EXIT89 (Kuligowski et al, 2005) shows that Simulex has a better performance to simulate a variety of occupant types and more realistically describes the interaction of different body types and travel speeds throughout stairwells.

SGEM (Lo et al, 2004)

SGEM is a relatively new evacuation model including a pre-processing engine to achieve the transformation from spatial information of CAD drawing into a network with a series of nodes. The movement of occupants is solved by a series of difference equations within a finite grid of cells. Once the calculation is finished, evacuation pattern can be visualised in the AutoCAD environment. The model is still being developed to account for the dynamic behaviour of people.

STEPS (Meacham et al, 2004)

The STEPS computer program is an optimization evacuation model being used on a wide range of projects in the field. It supports travel through various egress routes with the ability to establish a variety of egress paths in the model. Occupant characters are also defined in the model with the travel speed on horizontal surfaces and the behaviour for certain groups of people. This is another evacuation model that allows the import of CAD drawings as the input of building geometries. In terms of human reaction to fire threat, two functions are enabled, named "patience" and "families". These features estimate how likely an occupant is to stand in a queue or search out other people before leaving the building (Meacham, 2004).

SAFE-R (Gupta and Yadav, 2004)

The model applies an algorithm based on the network optimization theory and incorporates graph theoretical approach to identify the number of paths available for the movement of people. Travel time of each path and the number of people are calculated by the relationships developed from Stahl, Predtechenskii and Milinskii. By applying this algorithm, the prediction made by SAFE-R is quite close to the result determined by EVACENT+.

3.3 Study related to lecture theatre or stadium evacuation

Evacuation practice in the University of Canterbury campus (Olsson and Regan, 2001)

The study mainly focuses on the human behaviour under two different warning systems in three buildings. Two of them were tall buildings, which consist of offices, computer rooms, libraries, study rooms and lecture theatres. The other building was a one-story building housing three large lecture theatres. All buildings were equipped with emergency lighting, illuminated exit signs, evacuation alarms (which is a siren type system) and a pre-recorded PA message. People's reaction to different alarms was recorded with a video camera during the evacuation practice. It was found that the pre-movement times presented in current literature for office buildings and places of assembly seemed to be very conservative compared with measured time-lags. Individuals under announcement of pre-recorded PA alarm had shorter pre-movement than those in siren type alarm environments. As the evacuation time obtained from the experiment was for the entire building rather than individual rooms, it is not able to compare with the experiment results from this research.

Flow rate for design of stadium stairs (Brocklehurst et al, 2003)

In terms of crowd activity in buildings, poor information about the factors that may influence flow rates and the range of differences in flow rates under different conditions is given in current design guides. Thus, an experiment was carried out in Ascot Racecourse Stadium in the UK, by CICE department. Video camera footage was obtained of people leaving the stadium after a race meeting. From the data collected, a distribution of capacity flow rates was gathered for the circulation stairs. It suggests a lower value of flow rate, 66 people/metre/min to 68 people/metre/min, for the design of football and rugby stadium stairs, which is lower than the value, 73 people/metre/min, stated in the statutory document named “Green Guide” (The Scottish Office, 2003)

Stadium Venues in New Zealand (Hoskin and Spearpoint, 2004)

Another experiment related with movement behaviour of crowd group was conducted by Hoskin in Stadium Venues in New Zealand. The features of a stadium evacuation differ from normal egress process are discussed as (Hoskin and Spearpoint, 2004):

- The availability of exits that are not normally used is unpredictable due to the uncertainty of human behaviour.

- Limitations to visibility under emergency situations such as power failure or smoke obscuration.

- Audio and visual guidance from fire safety system

- Guidance or management from users and security personnel

The data for analysis was collected from 23 egress paths in various locations around the grounds of eleven New Zealand and Australian Stadiums. The data was compared with other references and calculations. The result showed that the current standard methods of anticipating egress movement when applied to stadium give a more conservative prediction than actual movement. In terms of crowd movement for very a large high density crowd, it has unique behaviour and special consideration should be given.

Self-Organized pedestrian crowd dynamics (Helbing et al, 2005)

A series of experiments were performed in order to investigate the crowd movement in corridors, bottleneck areas and intersections. From the evaluation of the video recordings, it was found that the geometric boundary condition was the crucial factor affecting the capacity of the elements of pedestrian facilities. Also, it had influence on the time gap distribution of pedestrians, which was referred to as self-organization phenomena. There were about 100 test persons involved in the experiments and the passageway boundaries were formed by tables instead of walls. Figure 3.8 to 3.10 show the different geometrical boundaries setup.

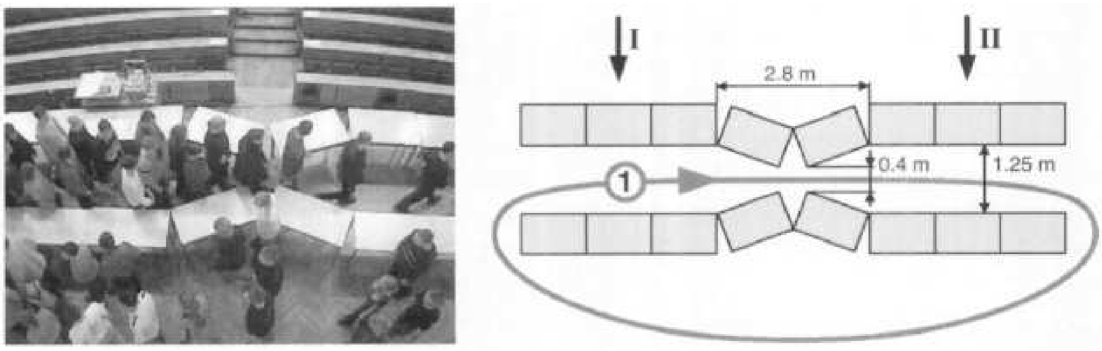


Figure 3.8: Unidirectional pedestrian streams passing a bottleneck (From Figure 4, Helbing, 2005)

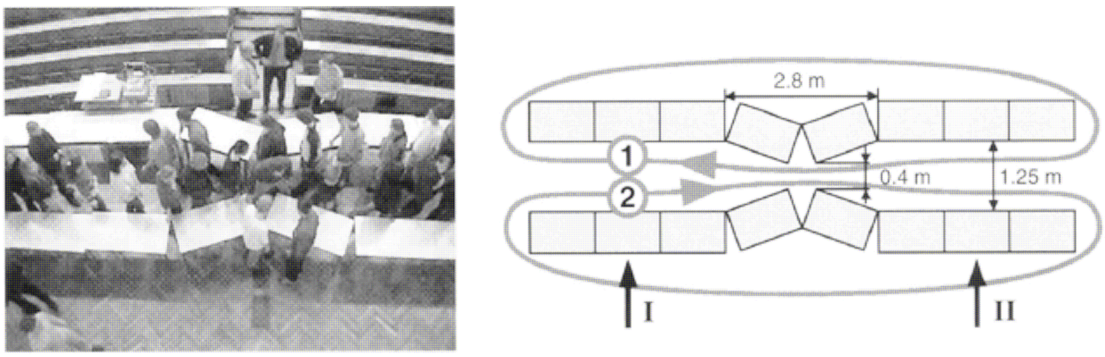


Figure 3.9: Pedestrian counterflows in a corridor with a bottleneck (From Figure 5, Helbing, 2005)

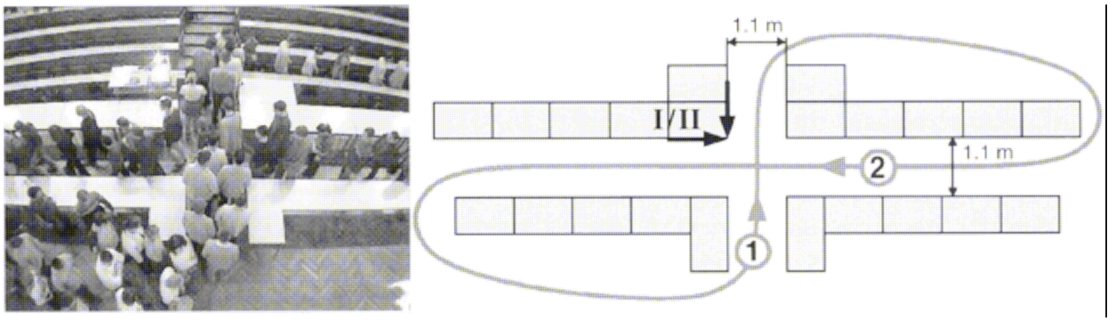


Figure 3.10: Intersection of two perpendicular pedestrian streams (From Figure 7, Helbing, 2005)

In addition, increasing diameters of egress routes in stadium, theatres, and lecture halls was suggested to prevent long queuing time for occupants in the back flow. A zigzag-shaped geometry was recommended for reducing the pressure in a panicking crowd. The proposed design solutions were expected to increase the efficiency and safety in diverse type of building. The modified geometry examples are shown in Figure 3.11 to 3.13.

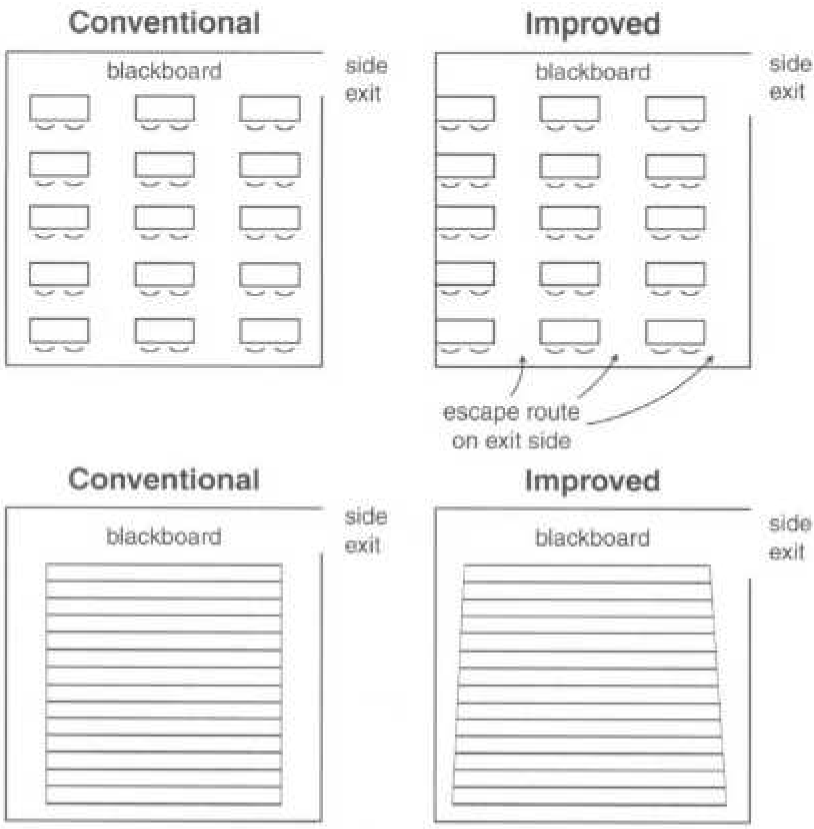


Figure 3.11: Modified layout of seats in a classroom and a lecture hall (From Figure 23, Helbing, 2005)

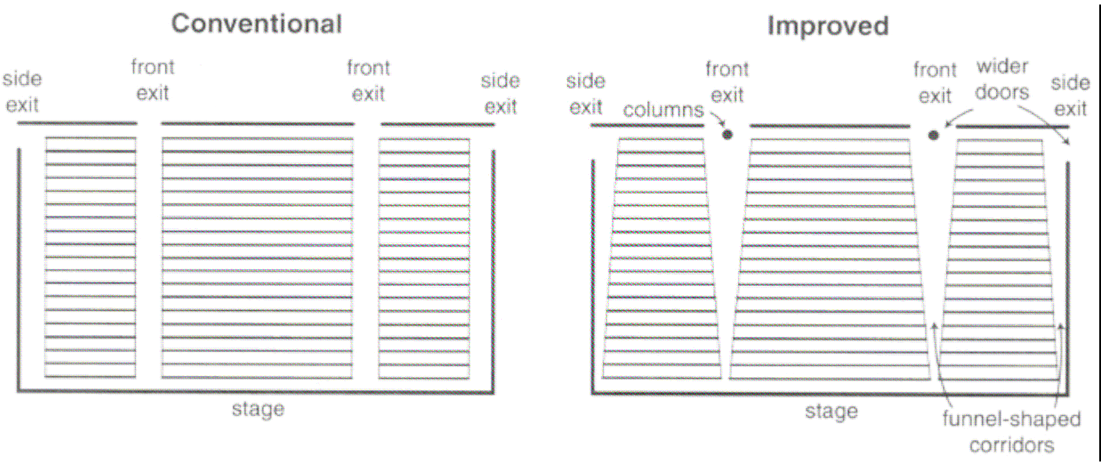


Figure 3.12: Modified layout of seats in a theatre (From Figure 24, Helbing, 2005)

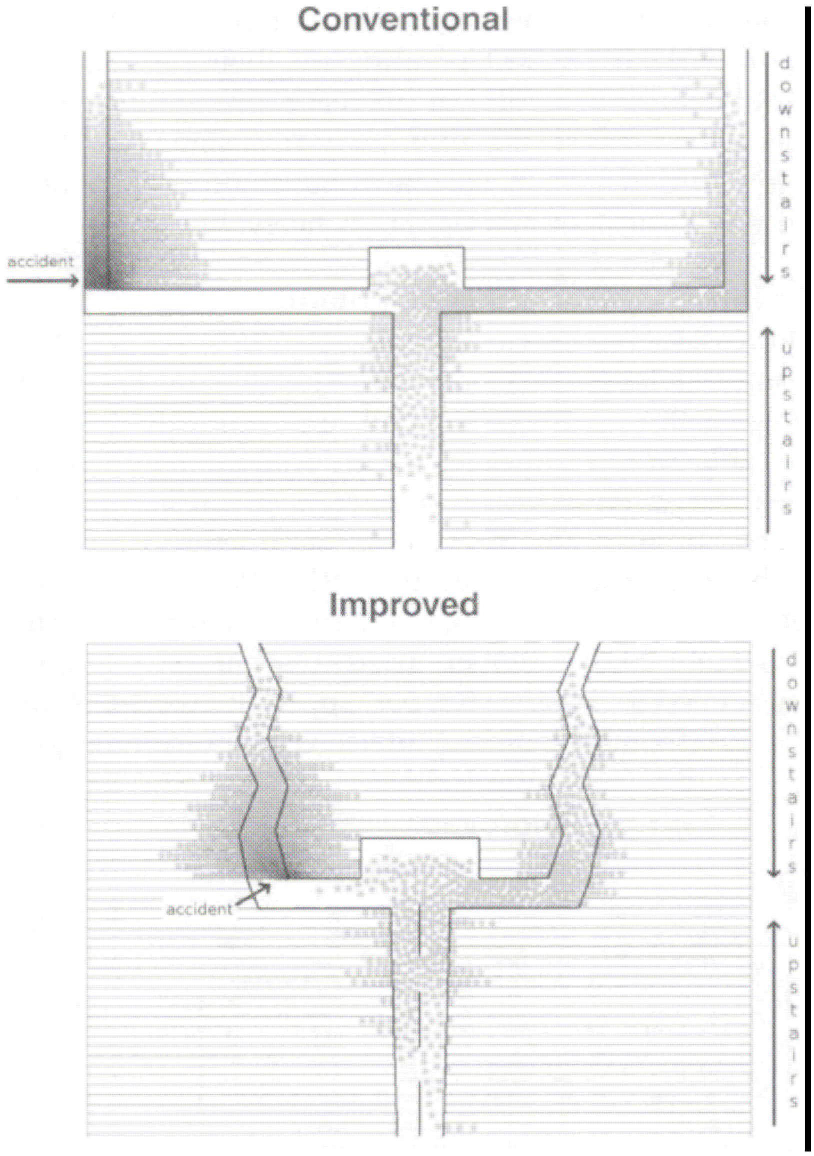


Figure 3.13: Conventional and improved design of a stadium exit (From Figure 25, Helbing, 2005)

3.4 Introduction of the EvacuatioNZ

The evacuation model, EvacuatioNZ, incorporates the Monte Carlo approach to produce probability distributions of evacuation time using a coarse network approach. The program is written in C++ language using Microsoft Visual C++ (Version 6.0). There are six elementary files requiring input of data which are MAP, POPULATE, SIMULATION, SCENARIO, PERSON TYPE and EXIT BEHAVIOUR. The first four files are related to the physical aspects and the last two files are related to the behavioural aspects. A detailed description of the input file can be found in Ko 2003.

Technically, this program is a node-based model, in which each component of the building is treated as a single node. The dimension of each node needs to be specified to enable the calculation of the maximum number of occupants in the node. To determine the distance between the nodes, the length from the corner of one room to the centre of the other room is represented as the actual travel distance in the model, for conservative estimation.

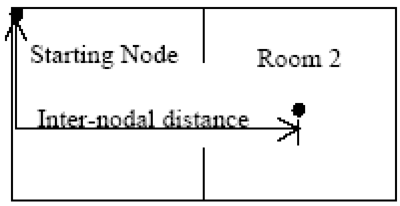


Figure 3.14: Inter-nodal path distance using in model

In terms of travel speed, it depends on the occupant density, age and mobility. In EvacuatioNZ, there are 3 types of movement speeds, the maximum walking speed, the travel speed and the path speed. The maximum walking speed is the speed that is only influenced by occupant's mobility rather than other factors. The travel speed is dependent on the occupants' posture. The path speed takes into account the occupant densities and connection types.

Generally, the travel time during the evacuation is determined by the inter-nodal path distance and travel speed. In EvacuatioNZ, the travel speed is expressed by the relationship from Nelson and MacLennan. However, these applications in EvacuatioNZ, especially the calculation for inter-nodal path distance and travel speed, are not appropriate for theatre-type buildings due to its complexity of seat layout. Mostly, the occupant density in this kind of building, suggested as 1.3 users/m^2, is relatively high (Buchanan, 2001). In addition, fixed seats in rows will restrict occupants' movement during evacuations. As a result, the travel speed will be dramatically decreased leading to the delay of egress time. Accordingly, the actual travel distance in theatres will be longer than the straight length from start point to final exit.

A systematical validation of EvacuatioNZ has been done by Teo. Various component testing was carried out to verify the performance of providing satisfactory results such as door queuing and movement on stairs. According to the validation, the model is able to produce comparable results to hand calculation.

Other research has been done on the validation of components of human behaviour in EvacuatioNZ and the model has been compared with actual incidents. It draws a conclusion that the current version is unable to model a theatre-type room accurately as a single node. Therefore, modification or new component needs to be worked out in order to advance the application of the model.

For a lecture theatre type of room, there is supposed to be a unique relationship between these variables, different from normal crowd behaviour. To progress the current version of EvacuatioNZ, investigation is required to find a new relationship which could more accurately describe the crowd movement in lecture room. This is assigned as the major objective of this research.

4 Methodology

In order to investigate crowd movement in a lecture theatre, a series of experiments was carried out to gather information for numerical analysis. A semi-annual evacuation drill is regularly organized with the co-operation of the Facilities Management Department and the Fire Service at the University of Canterbury campus in Christchurch, New Zealand. This practice is to assess the capacity of evacuation facility in every building. The experiment monitored the drill on 14 March 2006. In terms of the objective of this research, there are total eight lecture rooms selected in the experiment, located in Art Block (Lecture A1 ~ A3), Central Block (Lecture C1 ~ C3) and Science Block (Lecture S2 and S4).

4.1 Building description

The layout of buildings has an impact on occupant's decision making during the evacuation drills. People who are not familiar with the environment, are likely to spend more time obtaining information in a building where wayfinding is difficult.

4.1.1 Arts Block

Arts Block is a single-story building comprising three lecture rooms positioned triangularly. The three lecture rooms are combined with a foyer in the middle. The foyer is connected to the outside by four final exits on ground floor at each side of the wall.

For each lecture room, the entrance is 1.65m wide with double doors. There is also an alternative exit at the back of each room connected to a final exit on ground floor with stairs. Inside the room, the floor declines from upper back to lower front with a slope about 17 degrees. The total occupant capacity for three lecture room is about 600 people. It was noted that there was a class in all three lecture rooms at the time of the experiment.

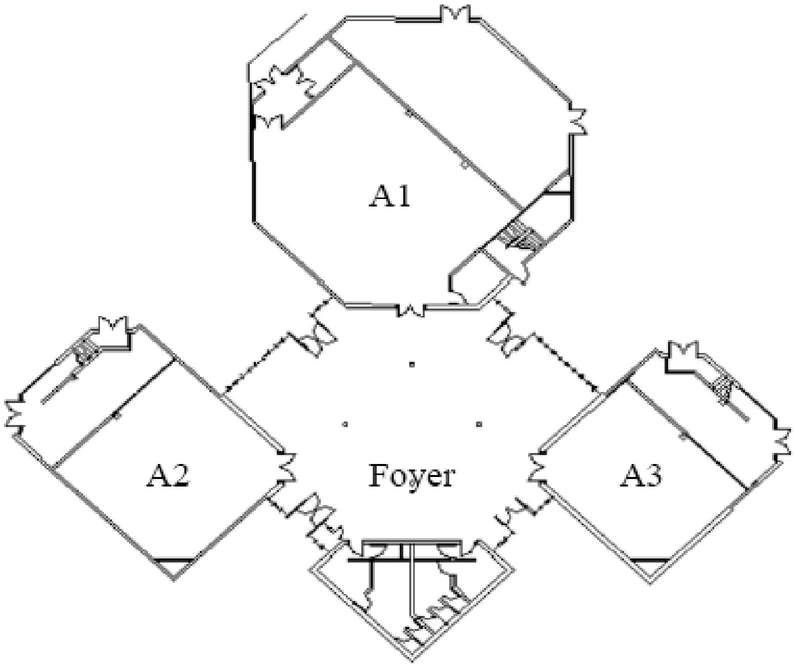


Figure 4.1: Layout of Arts Block (A1 ~ A3)

Figure 4.2: **Arts Block (Outside view)**

Figure 4.3: Central foyer of Arts Block

Figure 4.4: Final exit to the outside (Arts Block)

Figure 4.5: Entrance of Lecture A2

Lecture A1 is the largest room in the block with occupant capacity of 300 people. Except for two regular exits as the other two rooms, it also has a third means of egress route which is on the side against main entrance. From the inside, there is a small space connecting the final exit and the room exit. (See Figure 4.7)

Figure 4.6: The third egress route of A1 (Outside view)

Figure 4.7: The third egress route of A1 (Inside view)

4.1.2 Central Block

The central lecture theatre is a single-story structure with an intermediate floor. It consists of three large lecture rooms with egress routes to final exits at both ground floor and intermediate floor. On the ground level, two main entrances located at the left and right side of the building are connected to the outside. Two entrances of Lecture C1 and one entrance of C2 and C3 are in this level linked to a public foyer space. (See Figure 4.8) The width of the door is 1.5m for all three lecture rooms. On the intermediate floor, the back exit from each lecture room links to two final exits to the outside through a passage way. The exit door width is 0.75m. The occupant capacity for this block is about 800 people. C1 is the largest rooms with capacity of 400 people. Accordingly, four exits are applied in this room, two entrances in the front and two fire exits at the back.

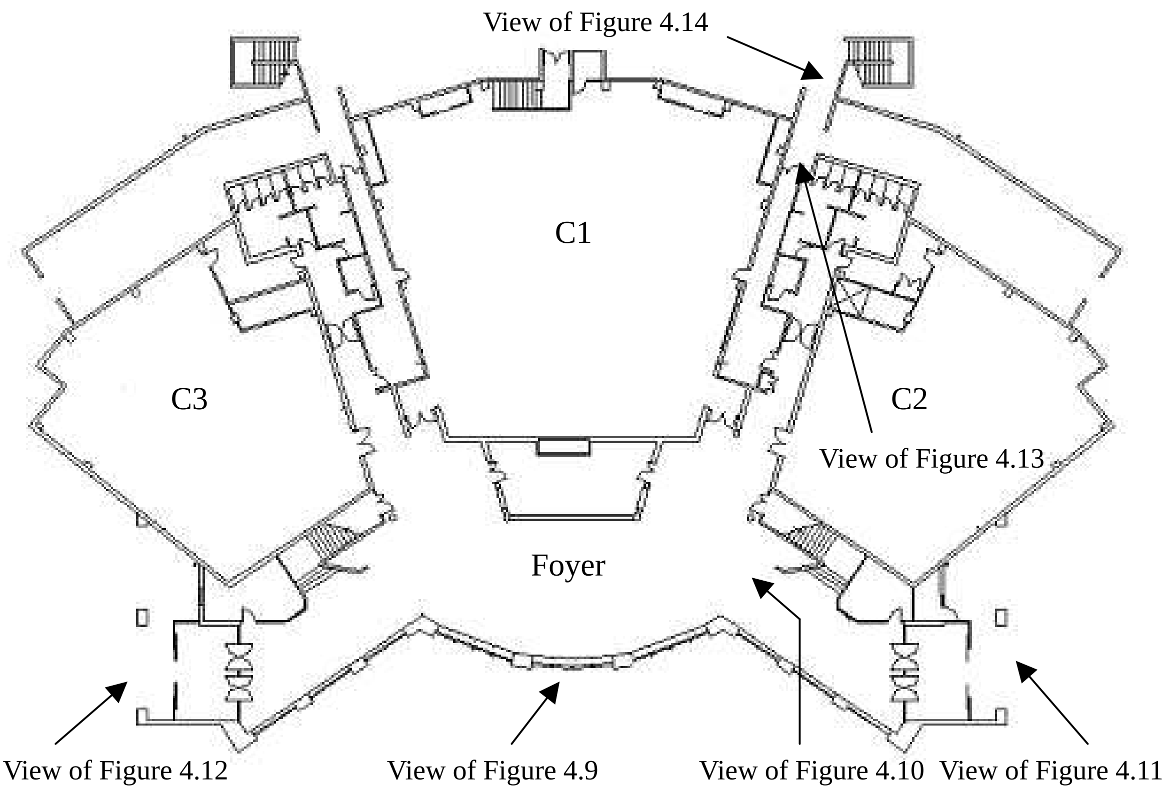


Figure 4.8: Layout of Central Block (C1 ~ C3)

Figure 4.9: Central Block (Outside view)

Figure 4.10: Intermediate floor of Central Block

Figure 4.11: Main entrance on right (C block)

Figure 4.12: Main entrance on left (C block)

Figure 4.13: Back exit of C1 (Inside view)

Figure 4.14: Intermediate exit (Outside view)

4.1.3 Science Block

The Science block is a multiple-story building with a total of eight different-sized lecture rooms. To focus on the objective of this research, the two large-sized lecture rooms on the first floor were selected in the experiment. On the ground floor, four final exits are located on each side of the wall of the building, one main entrance and three fire exits. Four stairs link to upper floor (First floor). On the first floor, four lecture rooms S1 ~ S4 are in the central space. Each room has two exits as egress routes, one at the front, and the other at the back connected with upper level by a stair as the room inclines from front to back. On this floor, there are another three exits linking to the other three buildings with a reconstructed corridor. At full capacity, this building can contain about 1000 occupants. The back exit, as an alternative egress route in S2 and S4, is located at the midway of auditorium area, not like other lecture which is room located at the back corner.

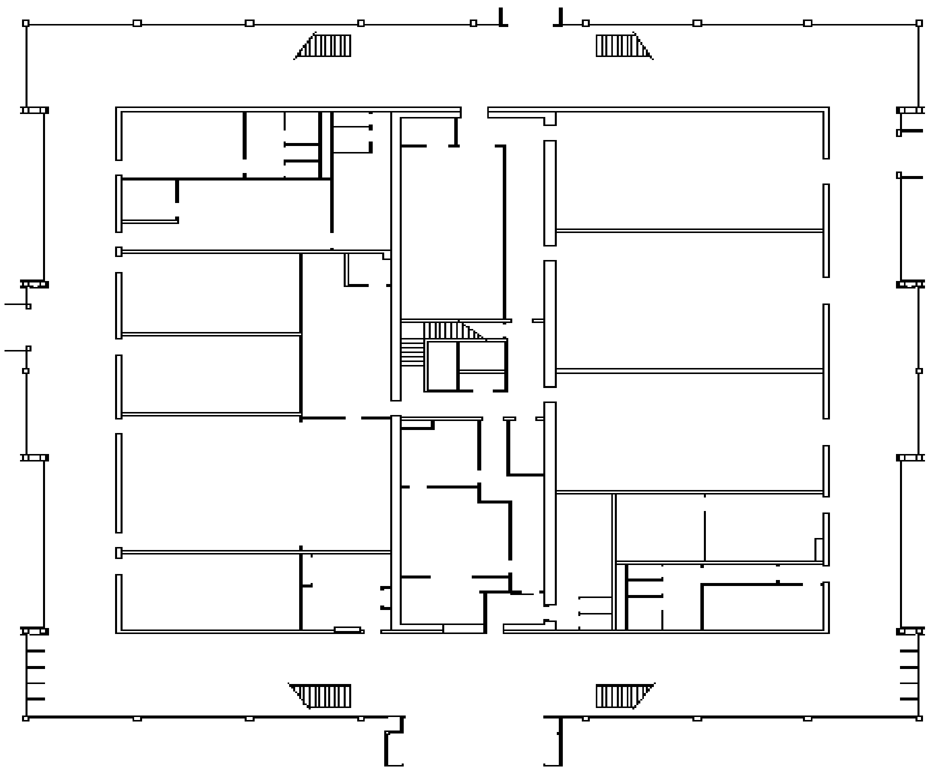


Figure 4.15: Layout of Science Block (Ground floor)

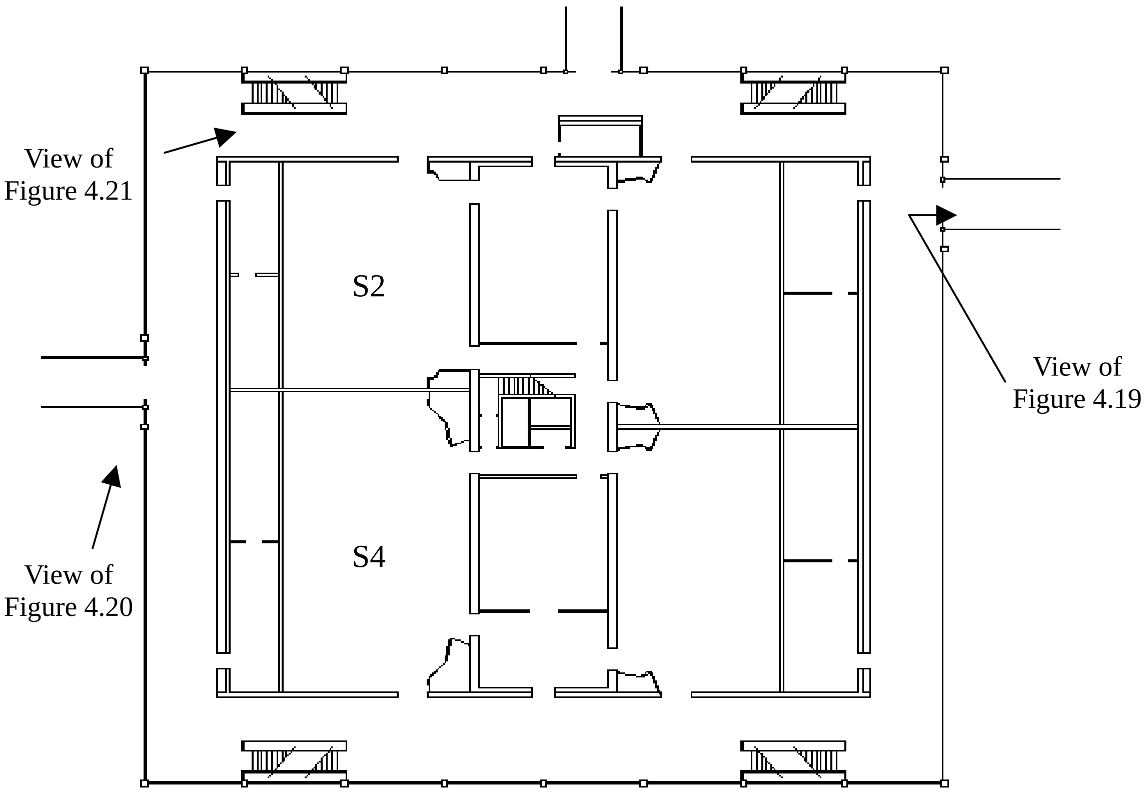


Figure 4.16: Layout of Science Block (First floor lower layer)

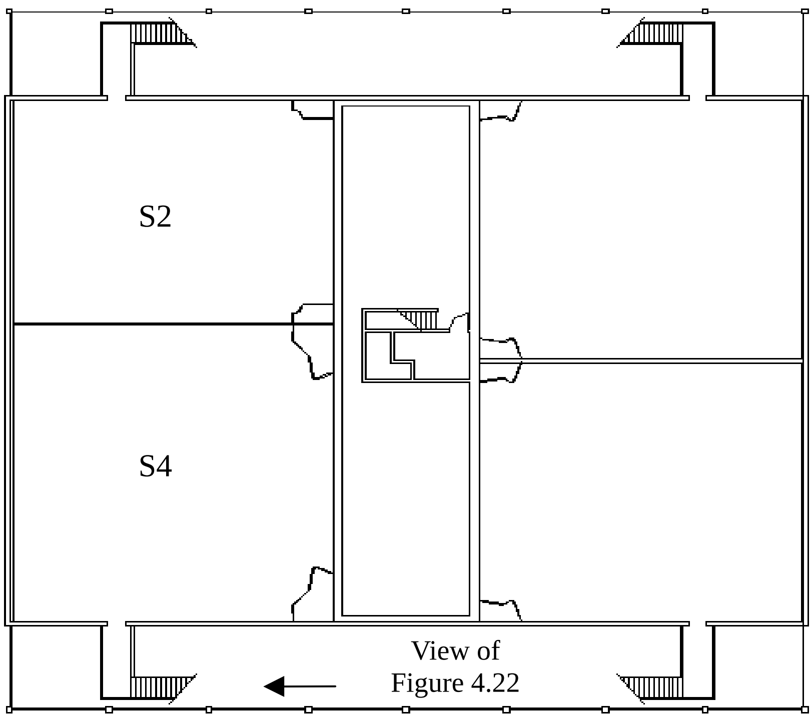


Figure 4.17: Layout of Science Block (First floor upper layer)

Figure 4.18: Science Block (Outside view)

Figure 4.19: Exit to other building (Inside view)

Figure 4.20: Exit to other building (Outside view)

Figure 4.21: Stairs to ground floor

Figure 4.22: Two egress routes of S2

4.2 Occupancy Characteristics

Generally, the occupant characteristics vary depending on the activities in the building. From observation, the majority of evacuees were students in their late teens to early twenties. Some of the evacuees were staff or lecturers of varying ages. In addition, it is presumed that the whole population is familiar with the building as they are full-time students using the lecture room for classes regularly. Since the evacuation drill is carried out throughout campus every half a year, it is also presumed that occupants have participated in evacuation drill before so that they are aware of the evacuation procedure and more likely to start evacuation rapidly.

4.3 Fire safety provision

All lecture theatres are equipped with a siren type evacuation alarm, emergency lighting system and illuminated exit signs. In The Science Block, in addition to a normal alarm system, a pre-recorded PA system is applied providing a voice message combined with a continuous signal with evacuation instructions. This improved warning system is considered to be high-level information, while a simple alarm (a sounder or bell), applied in C-block and A-block, is considered to be low-level information with a continuous signal. (Regan, 1998)

Figure 4.233: illuminated exit sign (Front)

Figure 4.24: illuminated exit sign (Back)

4.4 Procedure

Before the evacuation drill, the information pertaining to the building geometries was obtained from the building plans. The detailed information, such as the width of aisle and doorway, was measured manually beforehand. (Showing in Table 4.1)

Table 4.1: Measurement of building geometry

Location	Geometry (m)	Area (m^2)	Number of Exits (Main/alternative)	Door width (m)	Aisle width (m)
A1	20×16	320	1/2	Front:1.65 Back:0.75	1.2
A2	15×11	165	1/1	Front:1.65 Back:0.75	1.8
A3	12×10	120	1/1	Front:1.65 Back:0.75	1.8
C1	20×19	380	2/2	Front:1.50 Back:0.75	2.0
C2	17×15	255	1/1	Front:1.50 Back:0.75	2.0
C3	17×15	255	1/1	Front:1.50 Back:0.75	2.0
S2	13×12	156	1/1	Front:1.40 Back:0.90	1.5
S4	15×12	180	1/1	Front:1.40 Back:0.90	1.5

To achieve the aim of the experiment, permission was obtained from the Facilities Management Compliance Officer (Mr Pat Keogh) at the University of Canterbury. The exact date and time of the evacuation drill was also acquired from the officer.

There was one observer positioned at each exit of the lecture room. All of the observers were appointed to record the number of people exiting from the exit in a unit time. As the flow could be too intensive to record by hand once the evacuation process reaches a certain stage, a ‘Psion’ data logger was used for number counting, which can record the time when a number is manually input. The observers had been trained to use this equipment before the experiment. During the evacuation drill, they were positioned near each exit but did not interfere with the flow from the doorway. This provided valuable information about the flow rate under various conditions. The original evacuation data extracted from data logger is shown in Appendix A.

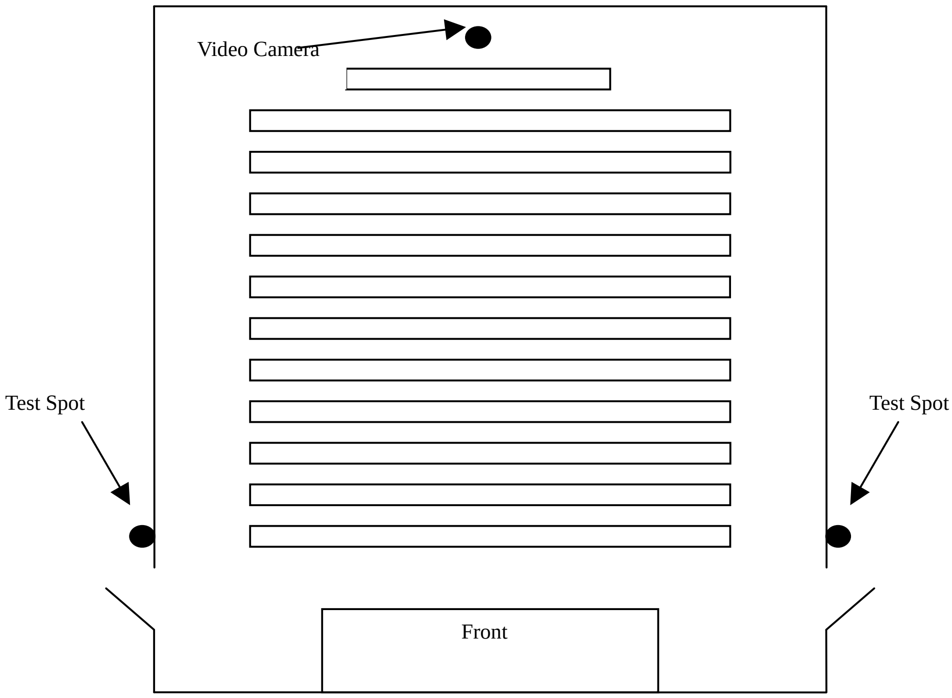


Figure 4.25: Schematic demonstration of an experiment setup

Figure 4.25 is a sketch of the experiment setup. The video recording was also carried out as another means of data collection during the experiment. This will be well discussed in the next section. According to the number counted by observers, some human error was recognized but the data is still available to do numerical analysis. Table 4.2 shows the number of people recorded from each lecture room.

Table 4.2: The number of people in each lecture room

Location	Number of ppl	Occupant capacity	Occupancy %
A1	246	300	82
A2	171	190	90
A3	96	140	69
C1	192	400	48
C2	186	200	93
C3	61	200	31
S2	100	170	59
S4	126	180	70

4.5 Video recording

Crowd movement in the lecture room was observed using video cameras. In order to have a good view of the entire auditorium area, the camera was set up in the projection room at rear, in which the recording could not be noticed by the majority of the occupants. Also, it provided a highest level of position as the camera had a view from the top down to the whole room. This prevented the blockage from the occupants when they were moving through the passage way at back. For the lecture rooms that projection rooms were not available, the camera was set at the back corner on each side. Due to the limitation of equipment and personnel, there were only three lecture rooms recorded by camera during the experiment. They were A1, C1 and S4.

Footage was transferred to digital data by a Microsoft Software called "Windows Movie Maker". Based on the footage, people's behaviour through the evacuation trial and queuing phenomena at doorway can be analysed by visual observation of video image and marking by hand.

Figure 4.26: Interface of "Windows Movie Maker" for video analysis

Figure 4.27: Projection room (Outside view) **Figure 4.28: Projection room (Inside view)**

Figure 4.29: Position of camera (Back corner) **Figure 4.30: Position of camera (Projection room)**

Figure 4.31: Camera view (Right side) **Figure 4.32: Camera view (Left side)**

5 Video Observation

The purpose of the video recording taken during the evacuation drill was to estimate the pre-movement time of occupants, location of congestion points, occupant density of crowd group and travel speed. Only the evacuation drills in Lecture A1, C1 were completely recorded. S4 was also recorded by camera but the position was not ideal and constant.

5.1 Pre-movement time

Pre-movement time is the time for occupant to perceive fire alarm, decide to take action and eventually get prepared to leave or seek refuge. In the experiment, this time is defined as the duration from activation of the fire alarm to the stand-up position for the majority of the occupants. Due to the camera’s position, the area around corner at the back of lecture rooms was not recorded. Nevertheless, the majority of the occupants recorded by the camera can reflect the general pre-movement time of each room.

According to the images captured during the experiment, there was a total of 187 and 119 people recorded by the camera in A1 and C1 respectively (Figure 5.1 to 5. 4). Due to the clarity of the images, some people in the front are not recognized or blocked by the people sat behind them. However, the proportion of the recognized people is high enough to present the whole group of student in the class by 76% in A1 and 62% in C1. White circles in the figures stand for individual persons.

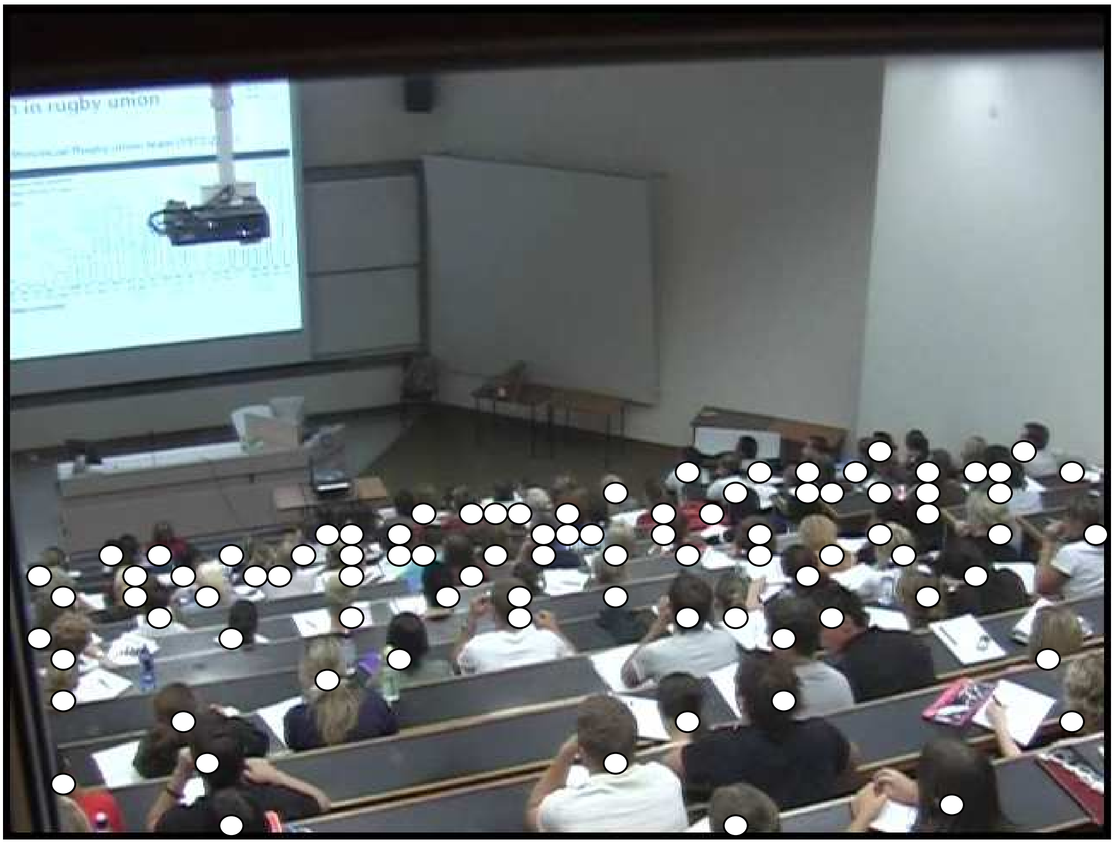


Figure 5.1: Image of A1 (right side) at the time alarm arise (90 people)

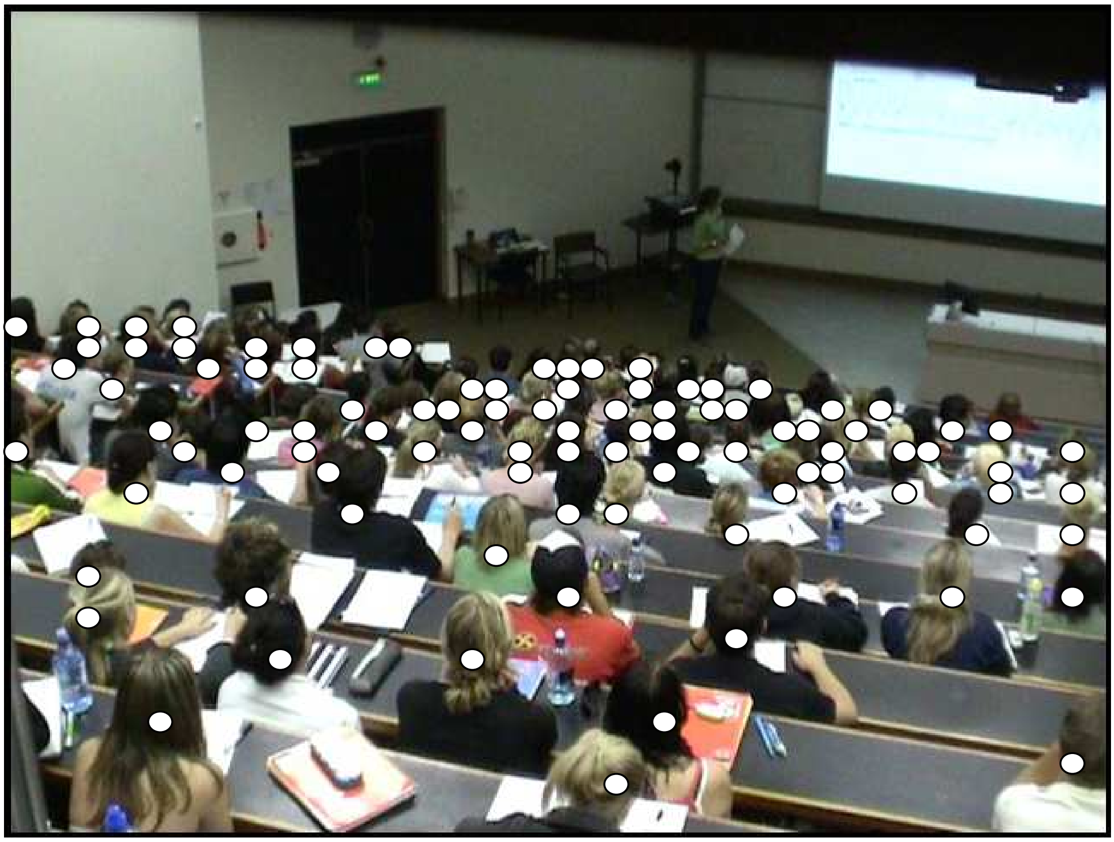


Figure 5.2: Image of A1 (left side) at the time alarm arise (97 people)

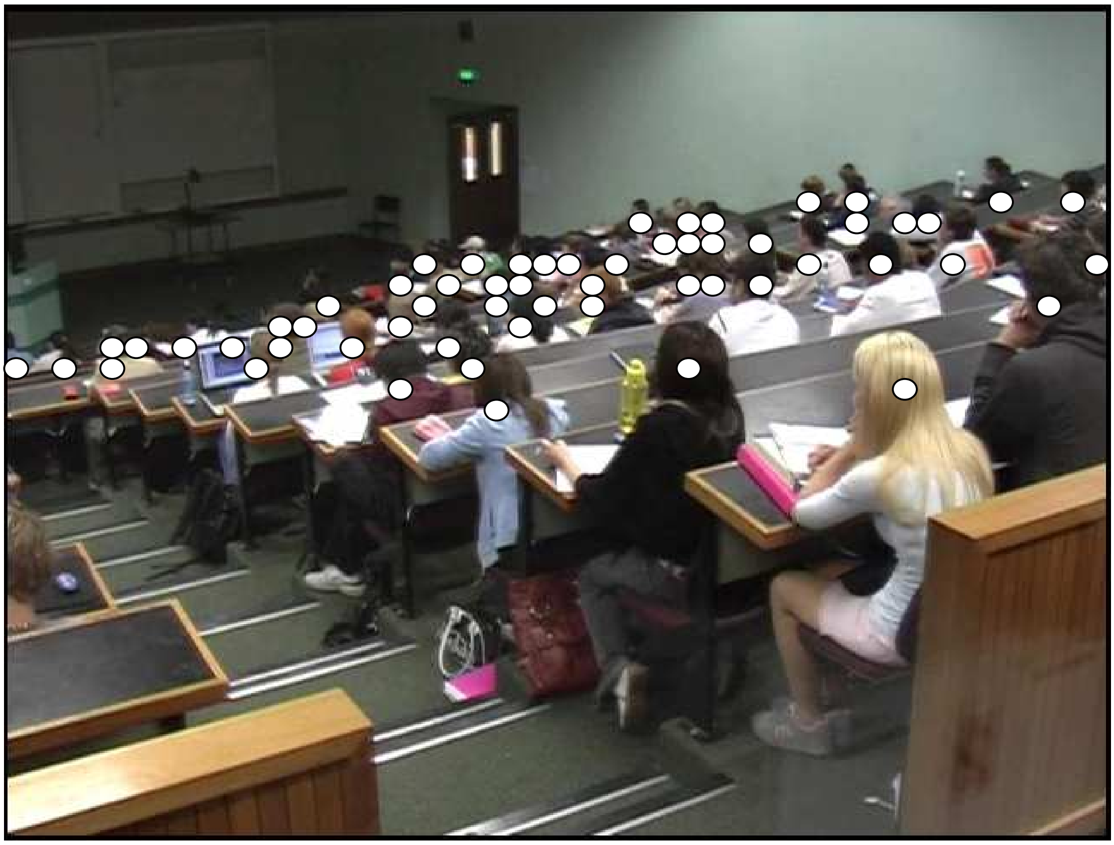


Figure 5.3: Image of C1 (right side) at the time alarm arise (58 people)

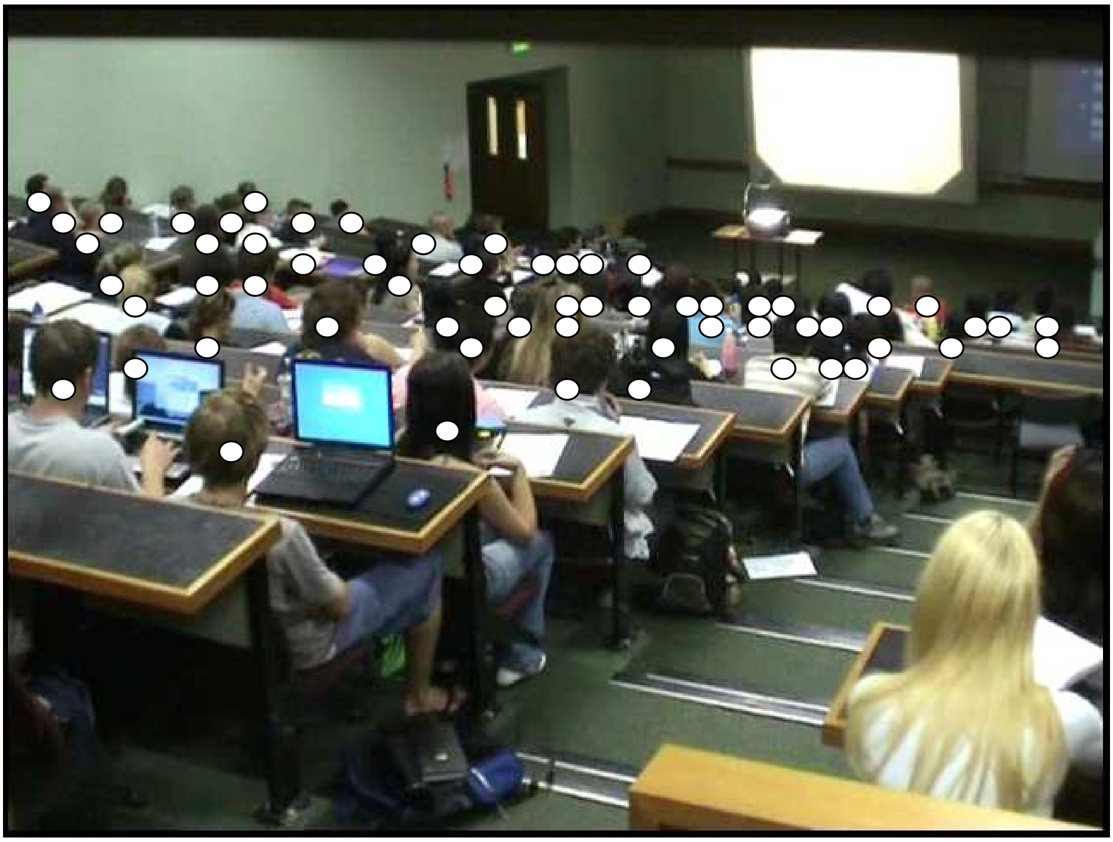


Figure 5.4: Image of C1 (left side) at the time alarm arise (61 people)

During the experiment, it was very difficult to identify the point for the whole group of students to reach the standby position as the time taken by each individual to make decision varies significantly. A front student had already evacuated the room whereas another student in the middle of the room was still packing up their belongings. Technically, it is very difficult to track such a volume of people by camera recording. Therefore, only an approximate estimation can be achieved through the video observation. It is assumed that the pre-movement is determined by the time over 50 % occupants are in stand-up position. Based on the observation, the estimated pre-movement times for A1 and C1 are 14 seconds and 22 seconds respectively. Figure 5.5 to Figure 5.8 shows occupants' positions by the time pre-movement actions were finished. Yellow circles represent the occupants standing up and white circles represent the occupants still seated. It is noticeable that the number of people counted in Figure 5.5 to Figure 5.8 is lower than the number in Figure 5.1 to Figure 5.4 because when people sit still in the class, it is much easier to count. Once people start to move around, more blockages occur in front of the camera causing miscount. Table 5.1 gives the detailed number of people and percentage of the people finished pre-movement action by the estimated time (14 seconds for A1 and 22 seconds for C1). According to the image taken at the estimated time, it can be seen that most of people at each end of rows stood up and were prepared to move to the aisle, while majority in the middle of rows (from 74.3% to 76.4% of the population) has packed up their belongings. Therefore, these estimated pre-movement times for A1 and C1 are appropriate to represent people's behaviour in the evacuation drills and will be used for later discussion.

Table 5.1: Number of captured people in the experiment

Location		No. of ppl captured at the beginning (Figure 5.1 to 5.4)	No. of ppl captured at designated time (Figure 5.5 to 5.8)	No. of ppl finished pre-movement action at designated time	Proportion of ppl finished pre-movement action
A1	left side	90	63	47	74.6%
	right side	97	72	55	76.4%
	total	187	135	102	75.6%
C1	left side	58	35	26	74.3%
	right side	61	47	35	74.5%
	total	119	82	61	74.4%

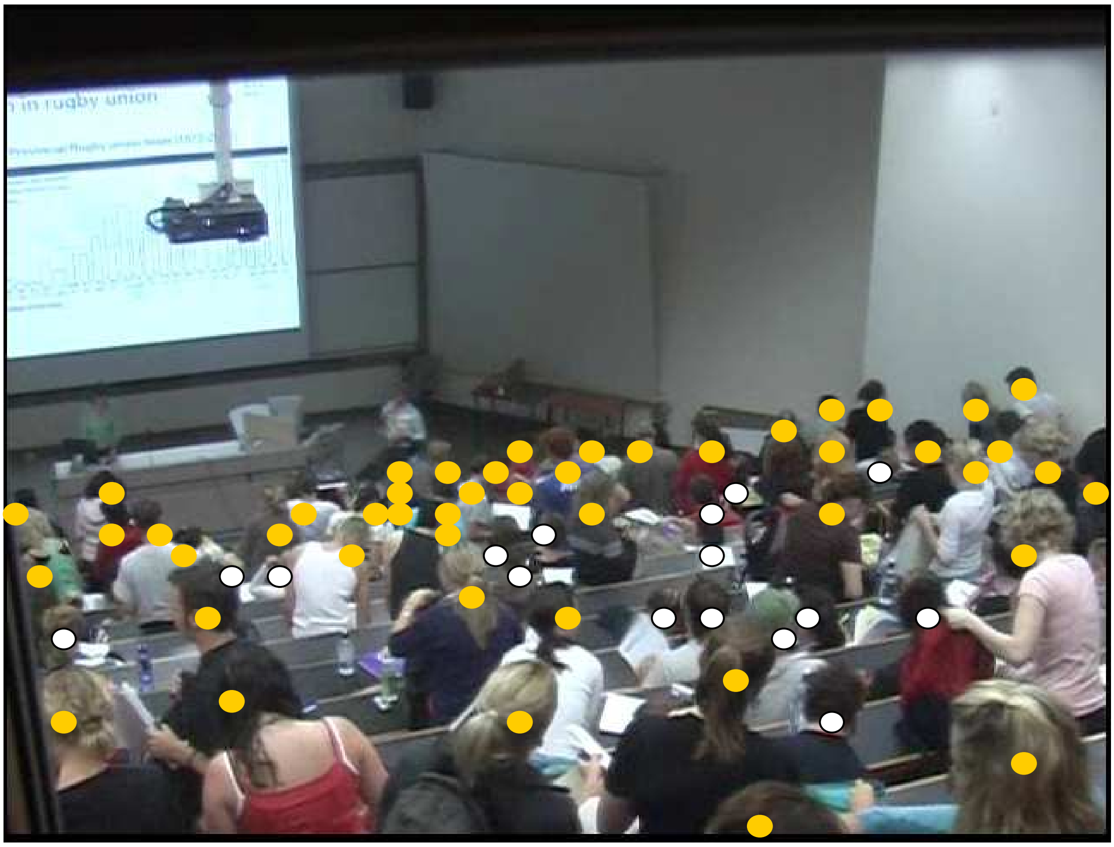


Figure 5.5: Image of A1 (right side) at 14s after alarm arise (63 people)

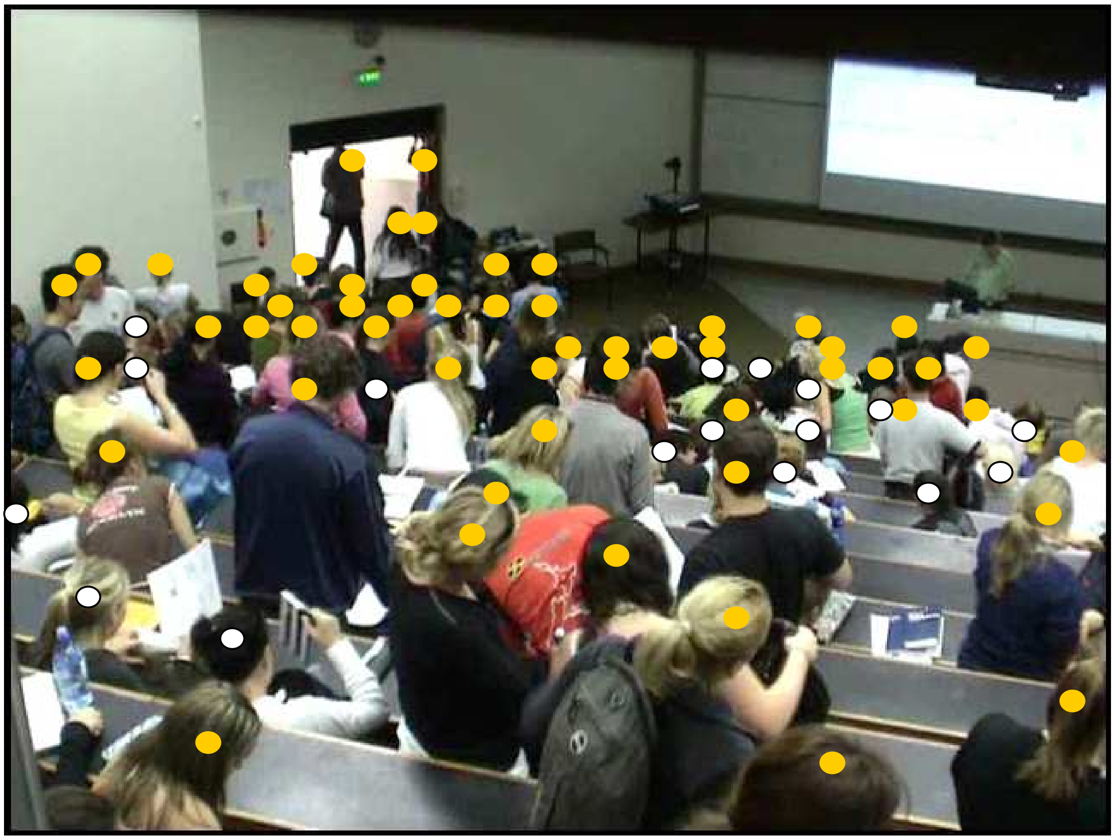


Figure 5.6: Image of A (left side) at 14s after alarm arise (72 people)

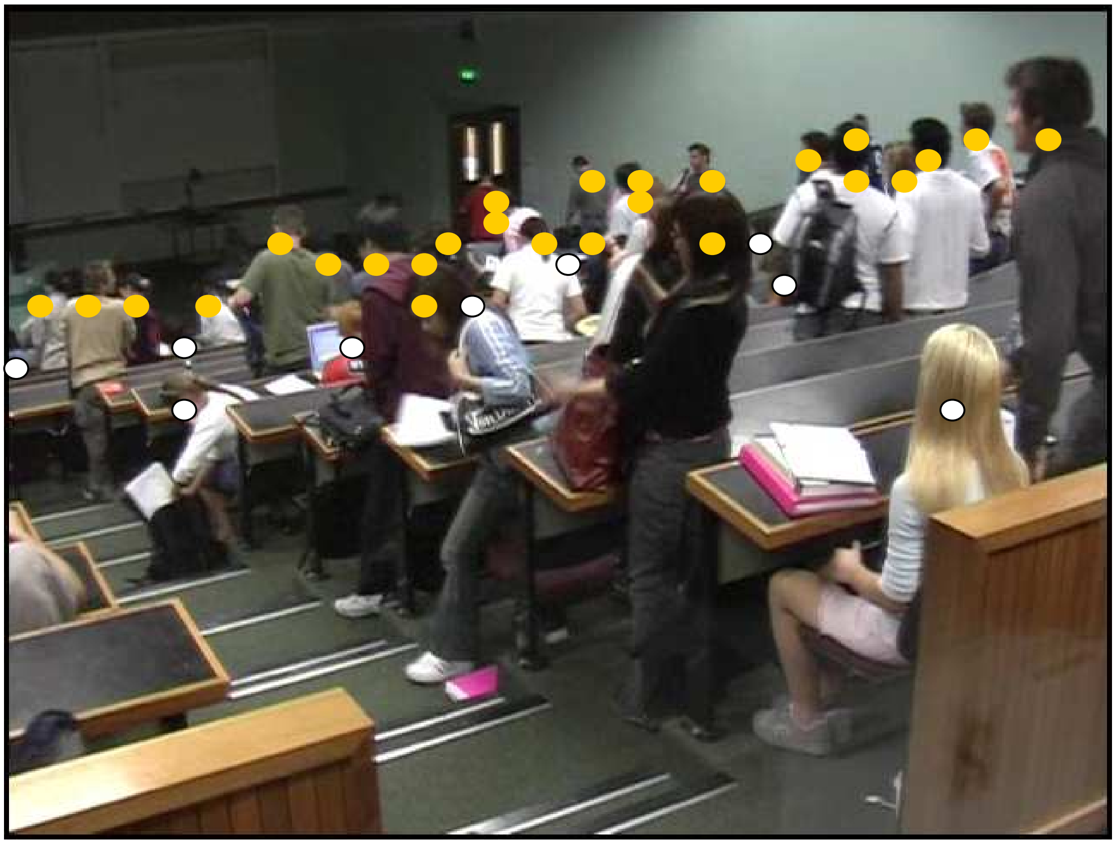


Figure 5.7: Image of C1 (right side) at 22s after alarm arise (35 people)

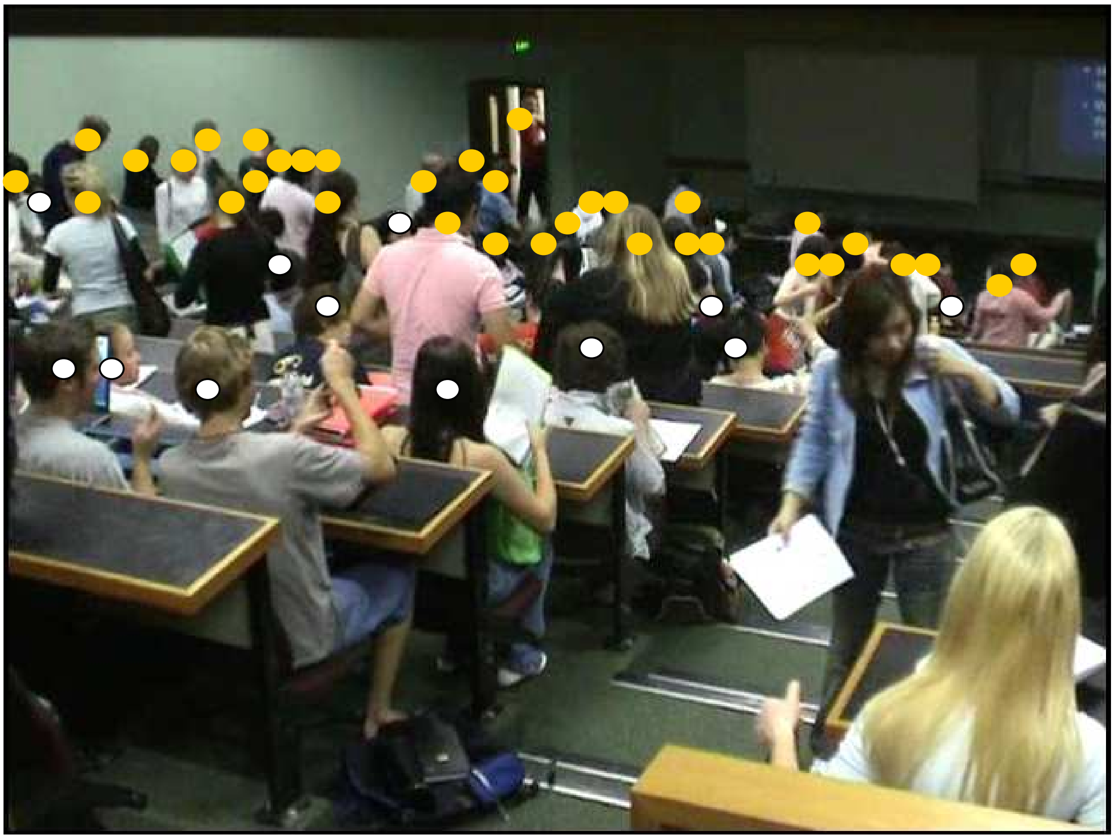


Figure 5.8: Image of C1 (left side) at 22s after alarm arise (47 people)

There are many factors that affect the pre-movement time. From this experiment, staff instructions can be regarded as the crucial practice to determine the duration of the pre-movement time. Compared with office building or other types of structures, a lecture theatre has a distinctive character in which most of occupants are gathered in a single space. People’s decisions will be strongly affected by the behaviour of others (regarded as group interaction). A well-trained lecturer can give the class a very clear and direct order. Accordingly, it will significantly reduce the time for students to make a decision. From the observation, pre-movement time in A1 (14s) is much shorter than C1 (22s) because of the clear instruction from the lecturer.

Another important factor determining pre-movement time, particularly for lecture theatre room, is the behaviour of the people located at the end of each row. As they are obstructing the path to the aisle, people in the middle have to wait until they respond. On the other hand, if most people in the middle have already responded, and are in stand-up status, this would make those people sit in each row ending accelerate their process of decision making. There are complicated psychological phenomena involved which are beyond the scope of this analysis.

Due to the limitation of facility and personnel, the evacuation process in other lecture rooms was not recorded or recorded incompletely (Lecture S4). In order to analyse the experiment data further, an assumption has been made that the pre-movement time for the rest of the lecture rooms in the experiment is taken from the average value in A1 and C1, which is 18 seconds.

5.2 Queuing

Queuing is one of the most significant phenomena during evacuation practices as it dramatically affects evacuation time, especially for the building with a high occupant density like a lecture theatre. Well designed seating layout in a lecture room could decrease the evacuation time due to the effective use of passage area, subsequently resulting in a shorter period of queuing in the doorway. .

From then video footage, it can be seen that throughout the evacuation process in A1, queuing mainly occurred within the aisle area connecting with each row instead of the doorway area where queuing would most likely occur in other types of buildings. This is because the flows from each row instantaneously merge into the aisle and fill up this area in a very short period of time. People have to stay in the aisle waiting for other people in the front to clear the doorway. Besides, the width of central aisles (1.2m) in A1 is narrower than the width of main entrance (1.65m). Based on bottleneck theory, queuing will occur at the narrowest point along the passage, therefore the queuing phenomena is very obvious along the aisle whereas people can pass through the door with their normal walking speed at main entrance in A1. Figure 9 is the image taken at 27 seconds after fire alarm arising. During the evacuation, the door was propped open by staff and the doorway was not fully occupied.

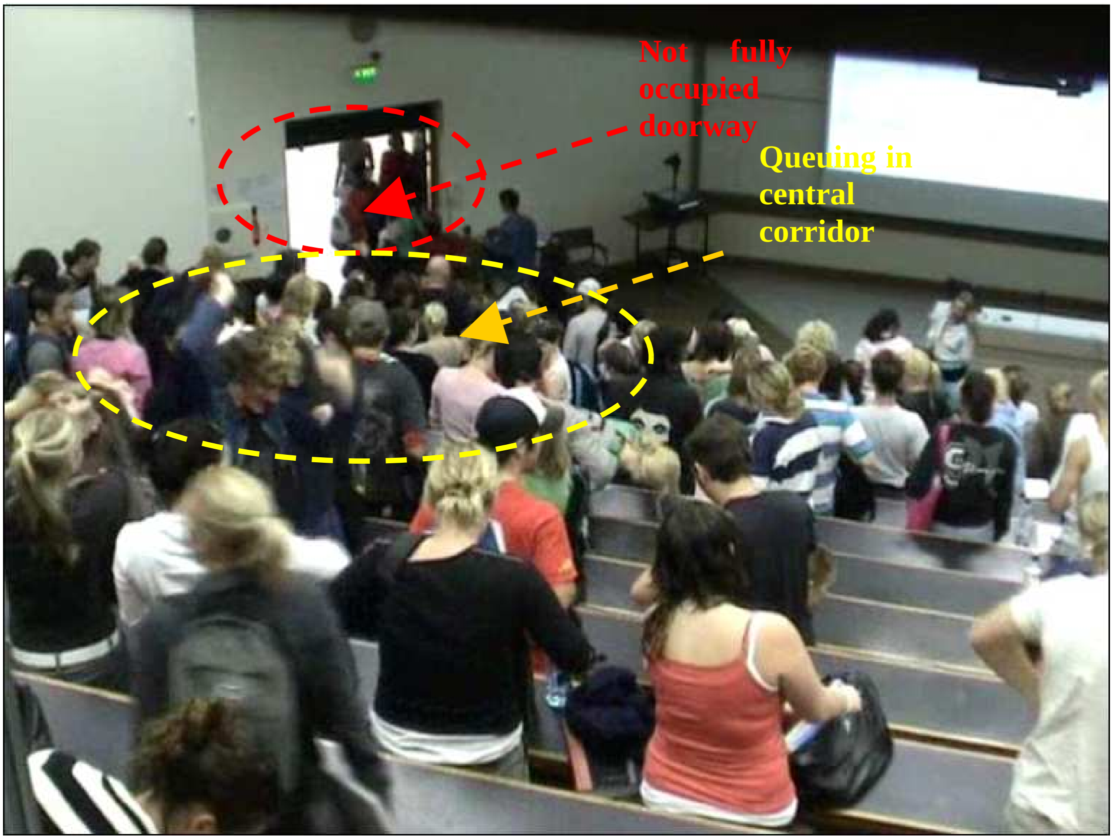


Figure 5.9: Queuing in A1 (27s after fire alarm arise)

On the other hand, the footage from C1 (Figure 5.10) shows that queuing in the central aisle is not as obvious as A1, as a result of the much wider aisles (2m) in the centre. Another difference is that the occupancy in C1 is only 48%, much lower than A1, where 82% of seats were taken up by the students who attended the class. This difference results in the low occupant density in aisle as there is not enough people to full in the area while others are departing to the doorway. The main entrance width in C1 is 1.5m, narrower than the width of the aisle. Theoretically following the bottleneck principle, queuing is supposed to be happening in the doorway area. In Figure 5.10, comparing with A1, the doorway is well used and there is queuing in the doorway area but this is not very obvious. This is due to an open space between these two areas, where the flow can spread out and reconcentrate to the next pass point. Figure 5.11 gives a schematic illustration of the flow along the passage. In addition, as a result of insufficient students, the low occupancy leads to an imperfectly continuous flow. This is another reason why queuing at the doorway is not obvious.

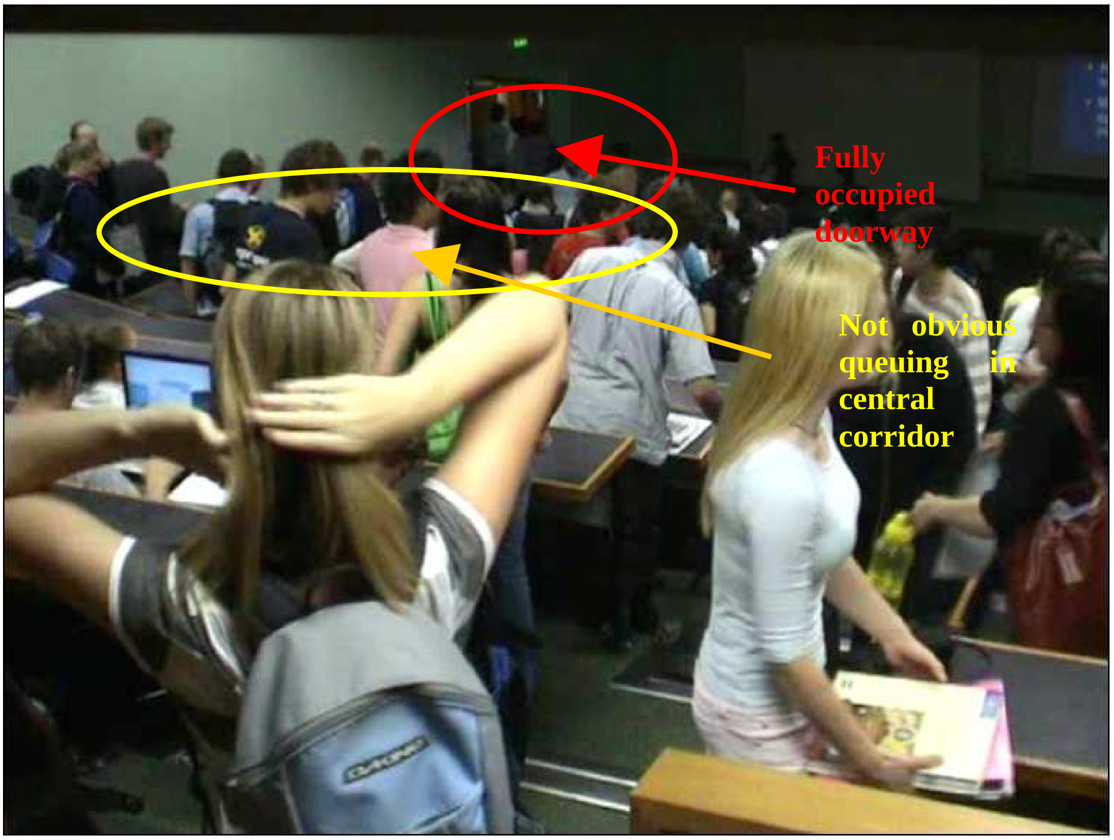


Figure 5.10: Queuing in C1 (35s after fire alarm arise)

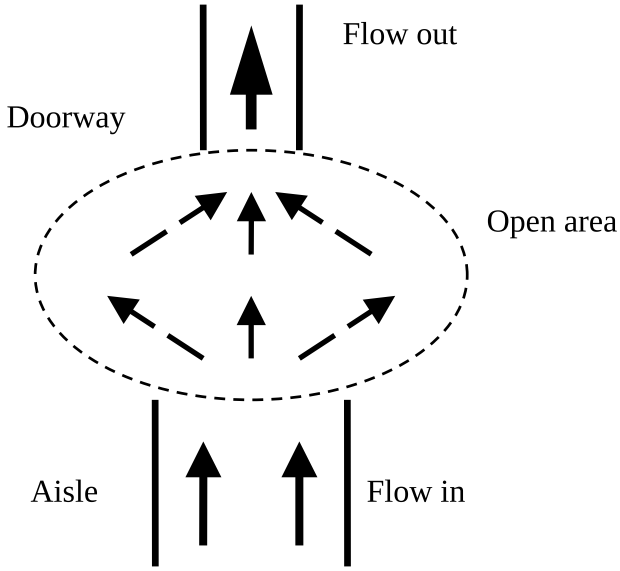


Figure 5.11: Sketch of the flow along the passage in C1

5.3 Exit choice

People usually choose to leave the same way they came in, even if there are other available exits much easier to reach. Behavioural science studies have found that people prefer to choose the known before the unknown (Benthorn and Frantzich, 1996). The knowledge of, and familiarity with egress routes by occupants is significantly important if fire exits are to be used during the evacuation process. In the case of this experiment, because occupants are students who attend class regularly and lecture room is open space without any blockage of vision, they are expected to be familiar with both main exit and alternative exit (back exit). Table 5.2 gives the percentage of people exiting from different routes. Exits at the back or side of room are regarded as alternative egress routes.

Table 5.2: Percentage of people egress from each exit

Lecture Room	Egress Route	Percentage of ppl, %
A1	Main Entrance	74.4
	Alternative Exits	25.6
A2	Main Entrance	71.4
	Alternative Exits	28.6
A3	Main Entrance	99.99
	Alternative Exits	0.01
C1	Main Entrances	62.5
	Alternative Exits	37.5
C2	Main Entrance	83.3
	Alternative Exits	16.7
C3	Main Entrance	86.9
	Alternative Exits	13.1
S2	Main Entrance	56
	Alternative Exits	44
S4	Main Entrance	50
	Alternative Exits	50

Generally, a proportion of people choose alternative exits. In this case, A3 is an exception due to the small class size with a majority seated at the front of the room. From the video record (Figure 5.12), although the back exit is not shown in the image due to the angle, it still can be judged that most people who sat near the back door chose the back exit because those people have not appeared in the flow down to the main entrance recorded by camera. This could be because the travel distance via back exit is shorter than the front exit, or someone opened the door which attracted others attention. More studies need to be conducted in order to make a clear conclusion.

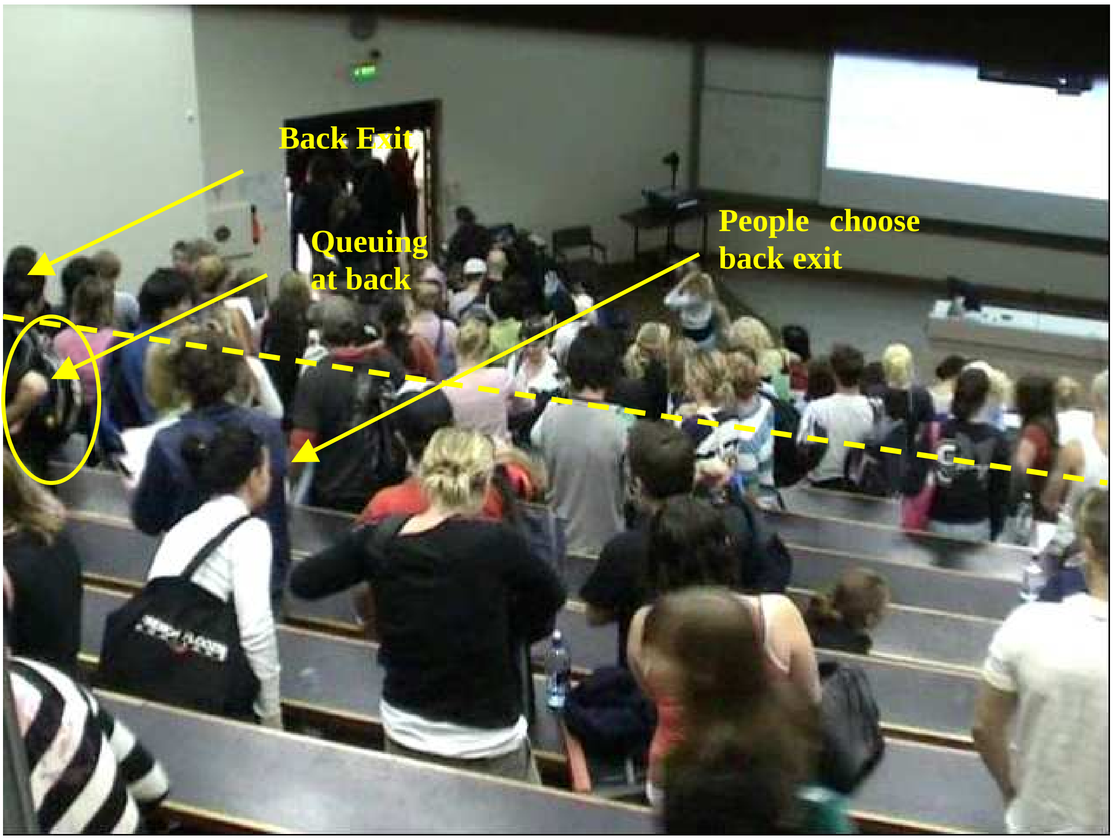


Figure 5.12: People choose back exit in A1

In table 5.3, the percentages of people choosing an alternative exit in S2 and S4 are relatively higher than other lecture rooms, 44% and 50% respectively. Compared with other lecture rooms, the most distinctive character of these two rooms is the location of the alternative exit, which is not normally at back, but in the middle of the side wall. (See Figure 5.13)

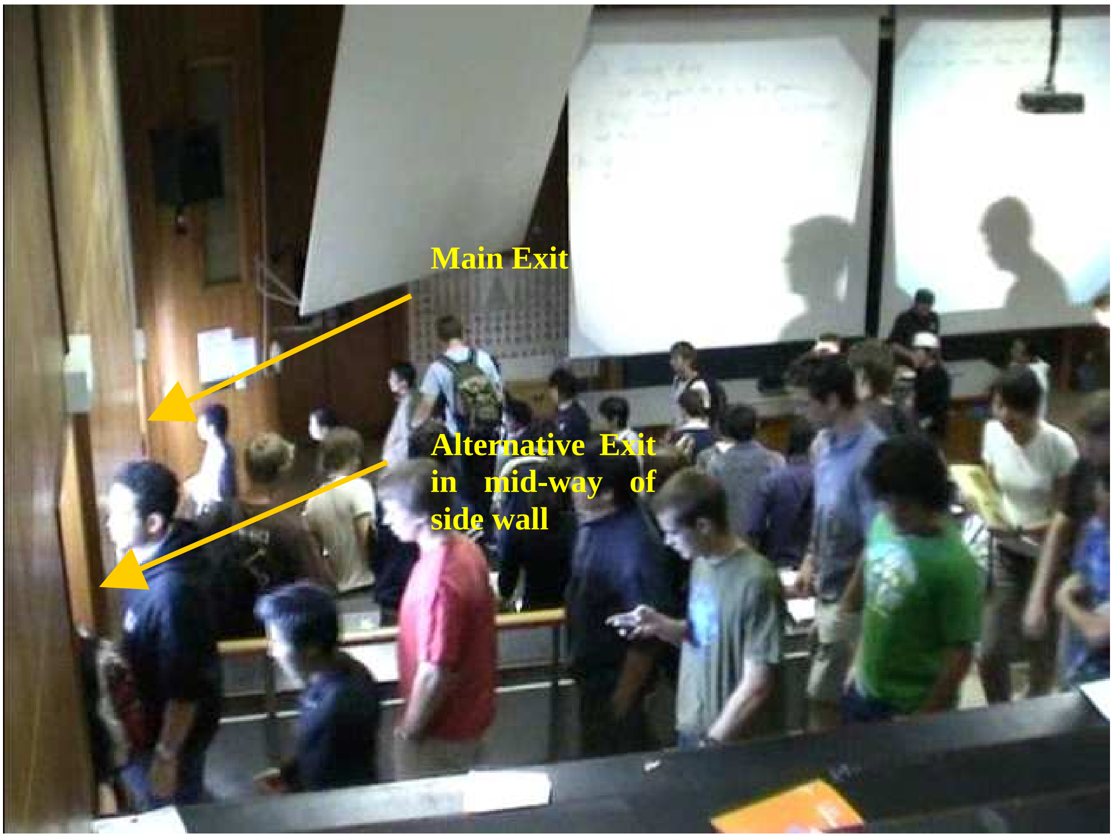


Figure 5.13: Location of exits in S2

This could make many people who are expected to choose the main entrance change their mind while they are looking for the nearest exit as the alternative exit installed on mid-way along the side is closer to more people. As a result, both egress routes are efficiently used by occupants. Thus, the evacuation time with this exit location is shorter than those with a normal exit location. Figure 5.14 gives a comparison between two locations of alternative exit.

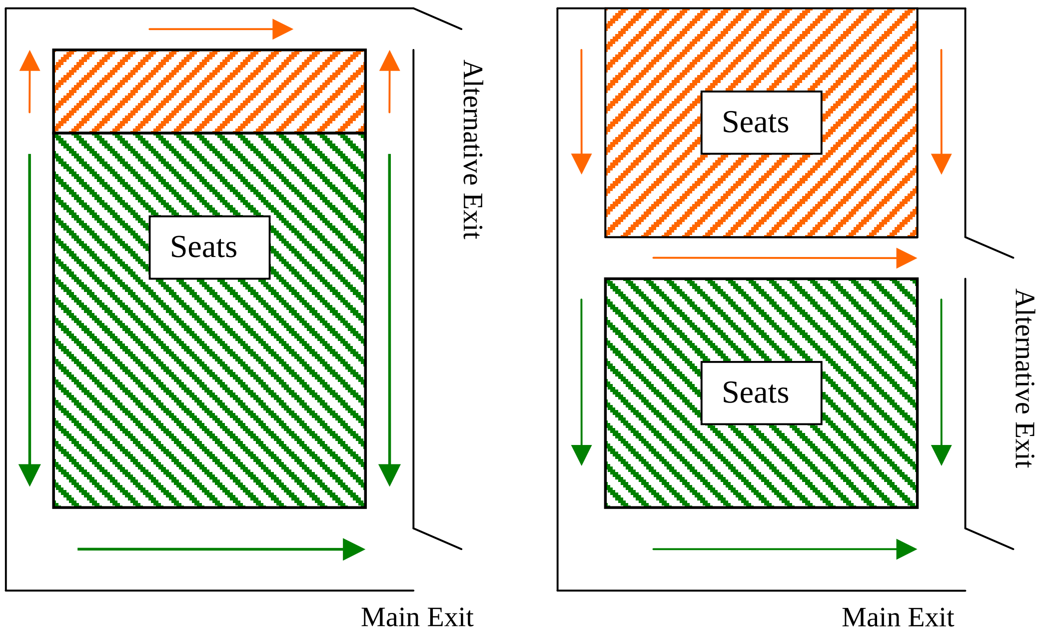


Figure 5.14: Sketch of exit choice with different location of alternative exit

Another interesting point observed is that most people sitting at the back half (except for the ones next to the back exit) prefer to follow the stream down to the front door, rather than waiting in the queue at the back exit which is much closer to them. This could be as the result of the slope of the aisle. From the start position, facing the front, it is more comfortable to move downwards. Because all of the lecture rooms in the experiment are sloping downwards, comparison of occupants' behaviour between flat-aisle and gradient-aisle room can not be achieved.

For lecture rooms, the distribution of occupants is another crucial factor affecting decision making as sitting location directly determines the distance to each exit. In the case of A3, where most people are sitting in front, there is low utilization at the back exits. This turns out to be extremely important under very low occupancy in the class.

Generally, many factors could determine occupant's decision making, e.g. layout of the room, location in the room or others behaviour. More detailed research could be done in this area.

5.4 Occupant density of crowd group

In order to do further analysis, the density of crowd group is an important parameter affecting evacuation time. Based on the images recorded during the experiment, the number of people in the aisle is counted every 10 seconds after the pre-movement time. Due to the set-up of the camera, the full-length aisle can not be completely accommodated in the field of view. The yellow dashed area in Figure 5,15 etc shows the area of central aisle which is used in density calculation. The instantaneous images for counting people are included in Appendix B. As most queuing took place within those areas, they turned out to be best choice for crowd density analysis. From Figure 5.16, these areas in C1 are not a regular shape. Therefore, an approximation is made that the width along the aisle is 2 meters. Instead of the central aisle, an area at the doorway is chosen in S4 due to the camera's position.

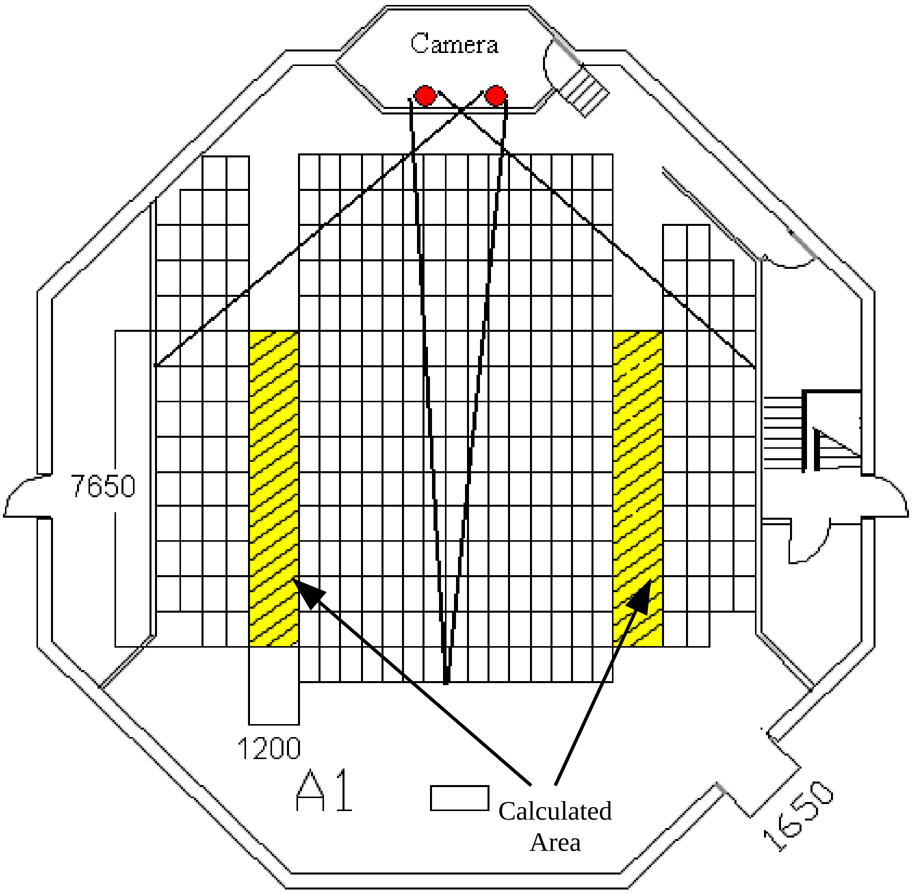


Figure 5.15: Area for density calculation in A1

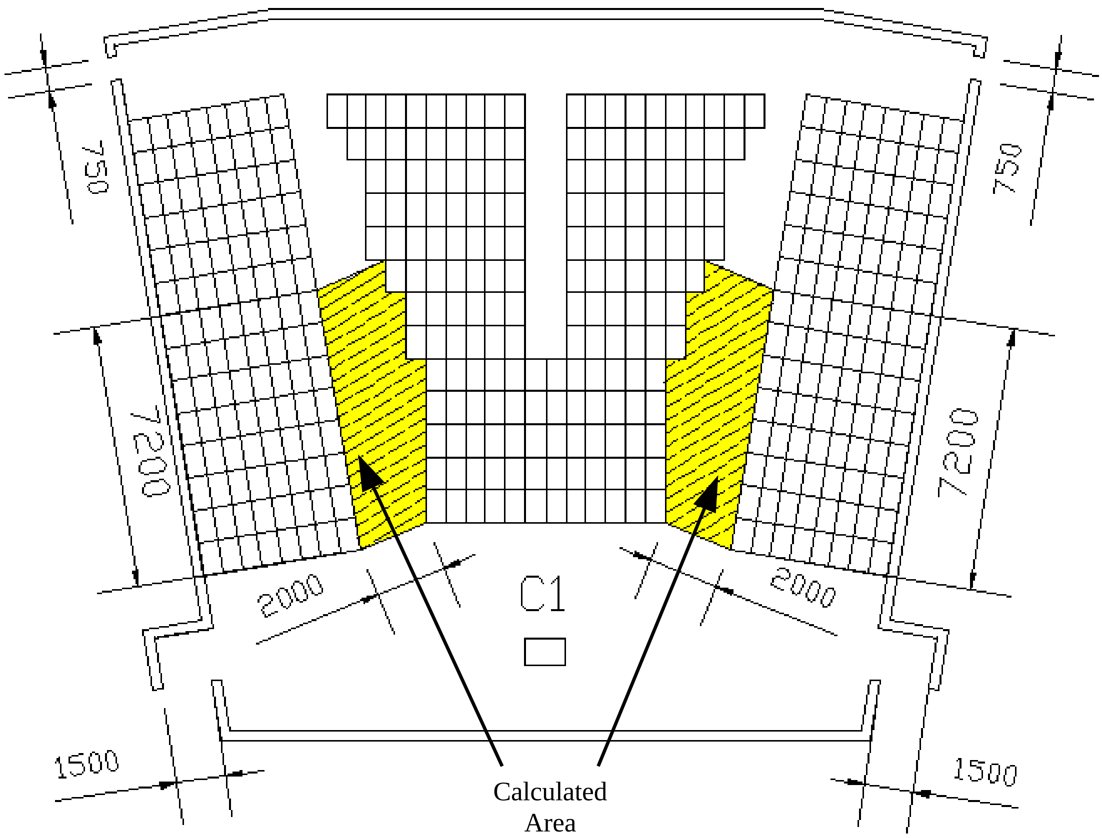


Figure 5.16: Area for density calculation in C1

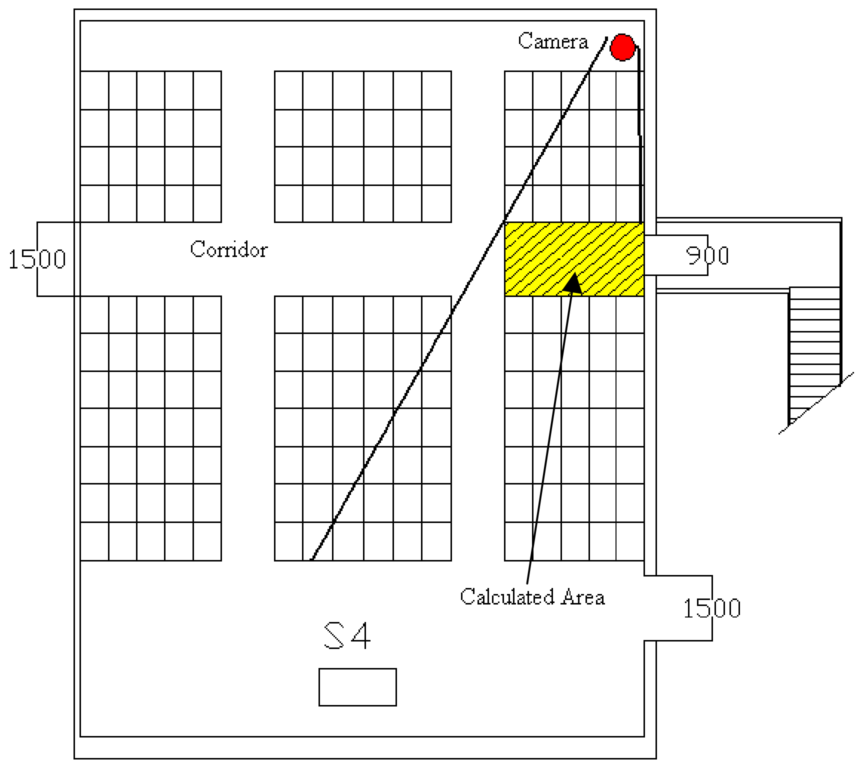


Figure 5.17: Area for density calculation in S4

As the resolution of the video images from experiment is not high enough to identify every single person within the selected area, errors from reality can not be avoided, it gives a comparable value to judge how crowded the aisle is. The SFPE handbook states: “if the population density is less than about 0.54 persons /m^2 of exit route, individuals will move at their own pace, independent of the speed of others. If the population density exceeds about 3.8 persons /m^2, no movement will take place until enough of the crowd has passed from the crowd area to reduce the density.” (Nelson and Mowrer, 2002) From the experiment results (See Table 5.3), the density of crowd group is 2.15 persons / m^2 in A1, 1.26 persons / m^2 in C1 and 1.82 persons / m^2 in S4. This density in all three lecture rooms is in the range, specified in SFPE handbook, which the travel speed is determined by occupant density. Therefore, it is worthwhile to discuss this parameter further.

One issue that needs to be noted is that the crowd density is continuously changing as time passes. The evacuation process continues and more and more people leave central aisle. After a certain point, there are not sufficient people filling up the entire designated area. In order to obtain an accurate density value, the number of people is counted at the time when designated area is fully occupied by occupants. Because of the shorter evacuation time in S1, only three worthwhile data points were collected.

Table 5.3: Calculated density of crowd group in A1, C1 and S4 based on video observation

Interval Time (s)	Number of people	Calculated Area (m^2)	Density (ppl/ m^2)	Average Density (ppl/ m^2)
A1 Right Aisle				
10s	20	9.2	2.2	2.24
20s	22		2.4	
30s	23		2.5	
40s	19		2.1	
50s	18		2.0	
A1 Left Aisle				
10s	20	9.2	2.2	2.06
20s	17		1.9	
30s	22		2.4	
40s	16		1.7	
50s	19		2.1	
C1 Right Aisle				
10s	18	13.6	1.3	1.2
20s	16		1.2	
30s	15		1.1	
C1 Left Aisle				
10s	18	13.6	1.3	1.32
20s	19		1.4	
30s	17		1.25	
S4 Central Doorway				
10s	9	4.8	1.9	1.82
20s	7		1.5	
30s	10		2.1	
40s	9		1.9	
50s	8		1.7	

5.5 Travel speed

The travel speed is another crucial parameter to determine the evacuation time. It varies within a wide range as the occupant density changes. To estimate the travel speed of the crowd group in lecture room, video imagery is used to collect necessary information. In order to obtain a well-representative value of the speed for crowd group, samples are chosen from five adjacent rows in A1 whereas three rows are chosen in C1 as the quality of the image in front row is not clear enough to recognize individuals. Three persons are selected in each row as the subjects to observe. The location of selected people in A1 and C1 is shown in Figure 5.18 to 5.21. According to video observation, most of the selected people were exposed to the stream when severe queuing occurred in the central aisle, which will give a more accurate travel speed corresponding to the crowd density.

The travel distance is the length of central aisle starting from the back of the row to the point where the flow spreads out at the front. It is shown in Figure 5.22 and 5.23. Each red solid circle represents a selected person. The travel distance gradually decreases by a row interval as position moves forward.

The travel time for each person is counted from the time when they merged into the main stream in the central aisle to the time they left the central aisle. The time spent on waiting in the row is not taken into account.

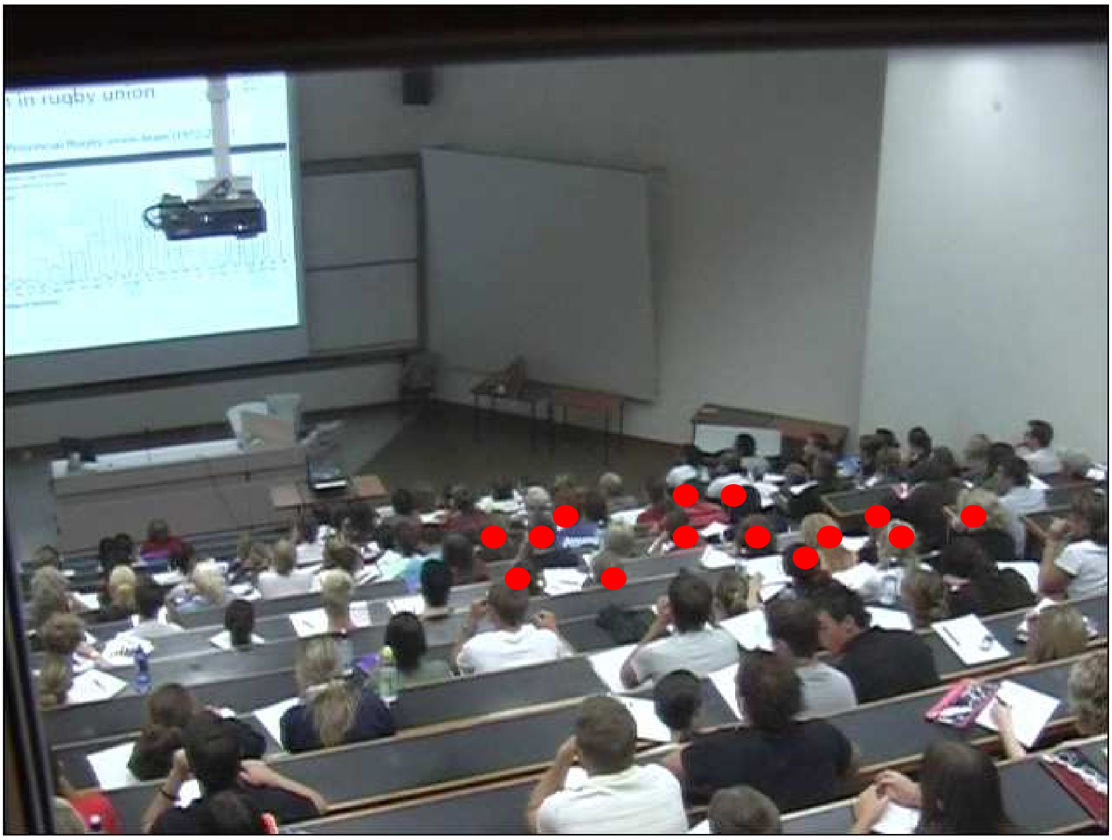


Figure 5.18: Location of selected people in A1 right side

Figure 5.19: Location of selected people in A1 left side

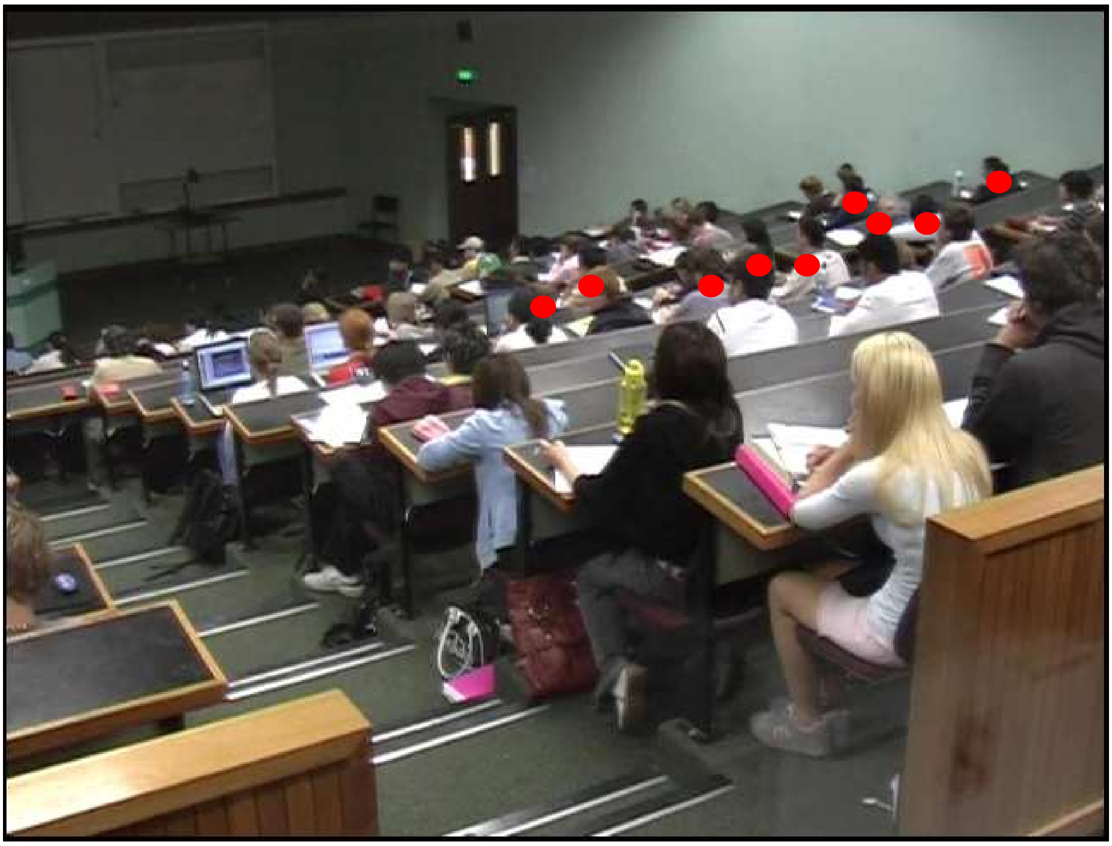


Figure 5.20: Location of selected people in C1 right side

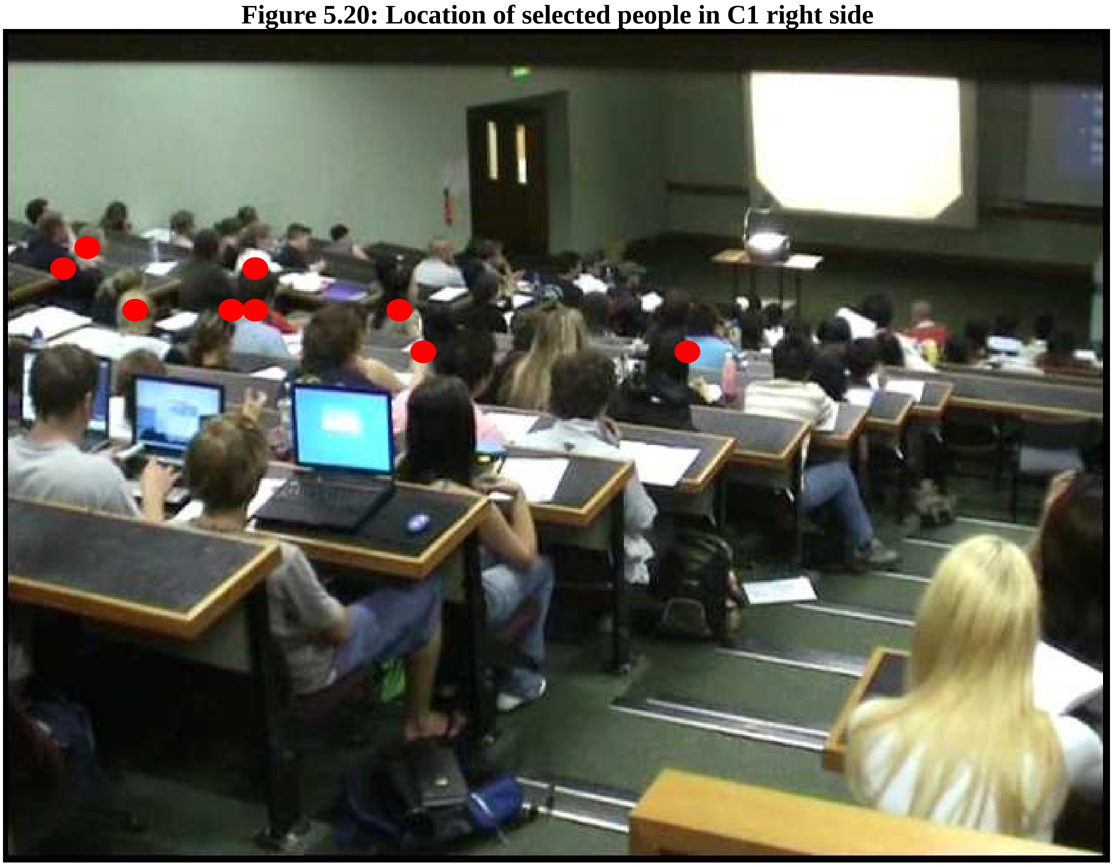


Figure 5.21: Location of selected people in C1 left side

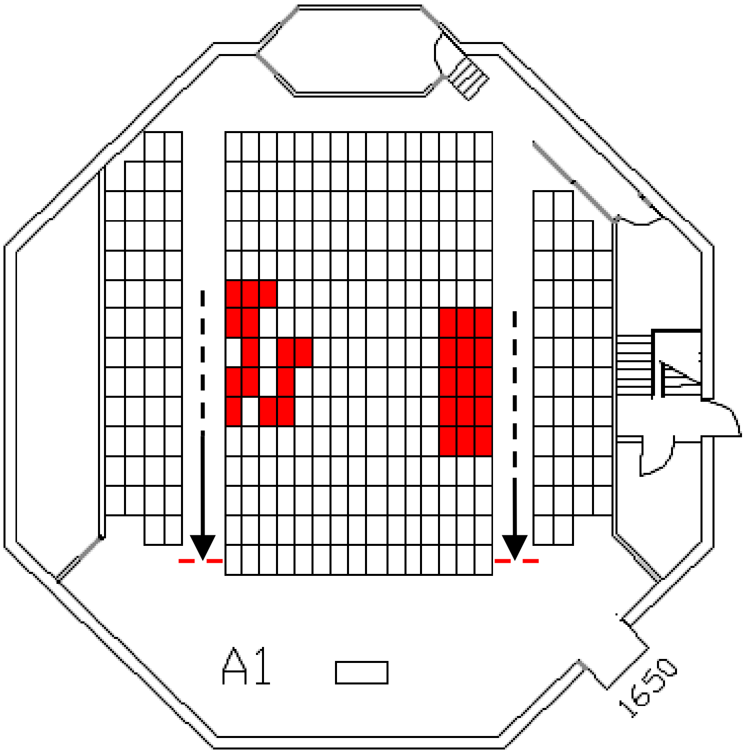


Figure 5.22: Location of selected people and travel distance in A1

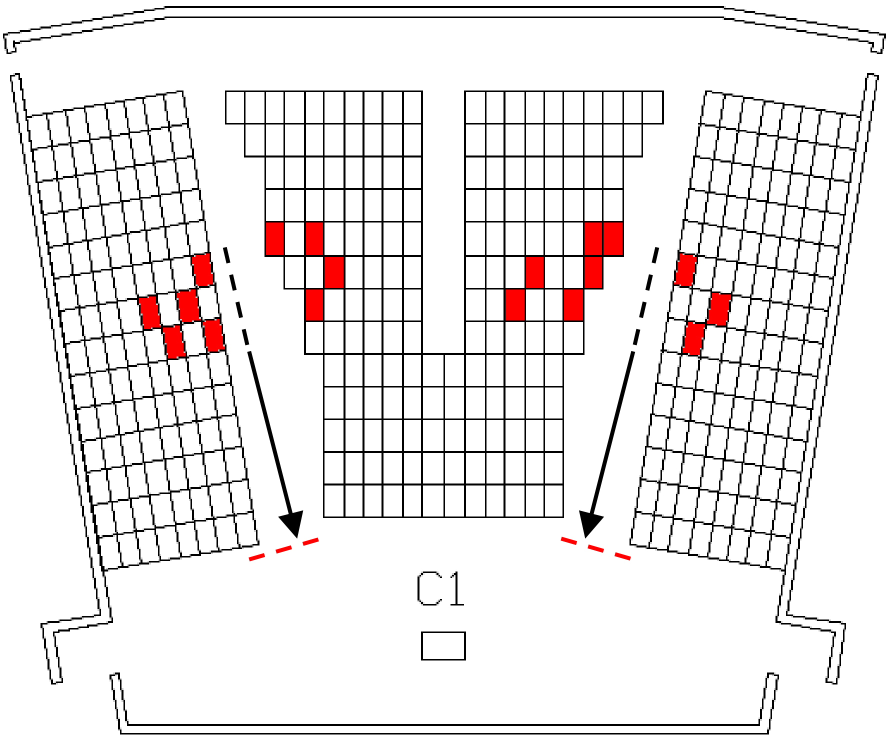


Figure 5.23: Location of selected people and travel distance in C1

Based on the travel distance and travel time, the actual travel speed can be calculated. The results are shown in Table 5.4. As a result of higher occupant density, very low travel speeds are obtained in A1 with an average value of 0.18m/s. C1 has a faster speed of 0.325m/s. From previous research, Predtechenskii gave an estimation of travel speed for pedestrian streams in rows of theatre from 0.3m/s to 0.45m/s in different intensity of occupant load. (Predtechenskii and Milinskii, 1978) According to observation, after people joined in the stream in central aisle, they stopped waiting in line rather than moving at beginning stage. Due to the technical limitation, this waiting time is also included in their travel time resulting in low travel speed. In fact, the speed they walked through the end point is faster then the average speed along the travel distance. Therefore, the experiment result has a relative agreement with previous work.

Table 5.4: Calculated travel speed of crowd group in A1 and C1

Location	Row	Travel distance (m)	Travel time (s)				Travel speed(m/s)			
			Person 1	Person 2	Person 3	Average	Person 1	Person 2	Person 3	Average
A1(right side)	10	6.8	49	48	41	46	0.14	0.14	0.17	0.15
	9	5.95	44	40	-	42	0.14	0.15		0.14
	8	5.1	18	33	31	27	0.28	0.15	0.16	0.20
	7	4.25	15	23	20	19	0.28	0.18	0.21	0.23
	6	3.4	18	16	15	16	0.19	0.21	0.23	0.21
	Average	5.1	29	32	27	30	0.21	0.17	0.19	**0.19**
A1(left side)	9	5.95	60	62	22	48	0.10	0.10	0.27	0.16
	8	5.1	43	44	43	43	0.12	0.12	0.12	0.12
	7	4.25	28	26	25	26	0.15	0.16	0.17	0.16
	6	3.4	24	25	12	20	0.14	0.14	0.28	0.19
	5	2.55	11	15	11	12	0.23	0.17	0.23	0.21
	Average	4.25	33	34	23	30	0.15	0.14	0.21	**0.17**
C1(right side)	9	6.8	13	10	25	16	0.52	0.68	0.27	0.27
	8	5.95	19	19	17	18	0.31	0.31	0.35	0.33
	7	5.1	12	11	17	13	0.43	0.46	0.30	0.40
	Average	5.95	16	15	20	16	0.37	0.39	0.31	**0.33**
C1(left side)	9	6.8	26	20	18	21	0.26	0.34	0.38	0.33
	8	5.95	10	20	16	18	0.60	0.30	0.37	0.33
	7	5.1	19	21	12	17	0.27	0.24	0.43	0.31
	Average	5.95	23	20	15	19	0.26	0.29	0.39	**0.32**

A few data sets are not taken into account for average speed (with solid oval in Table 5.4) as the person with that speed, responding faster than others, travelled downwards without encountering queuing. In other words, the pre-movement time of the person is shorter than the majority's. They were moving down with normal walking speed while others were still in their decision making process.

Another phenomenon is that generally people sitting in the back rows have lower travel speed than ones sitting in the front. It can be interpreted as that the people at the back have to wait longer time for people in the front to get out, as well as the merging flow from front rows into the main stream. This is illustrated in Figure 5.24.

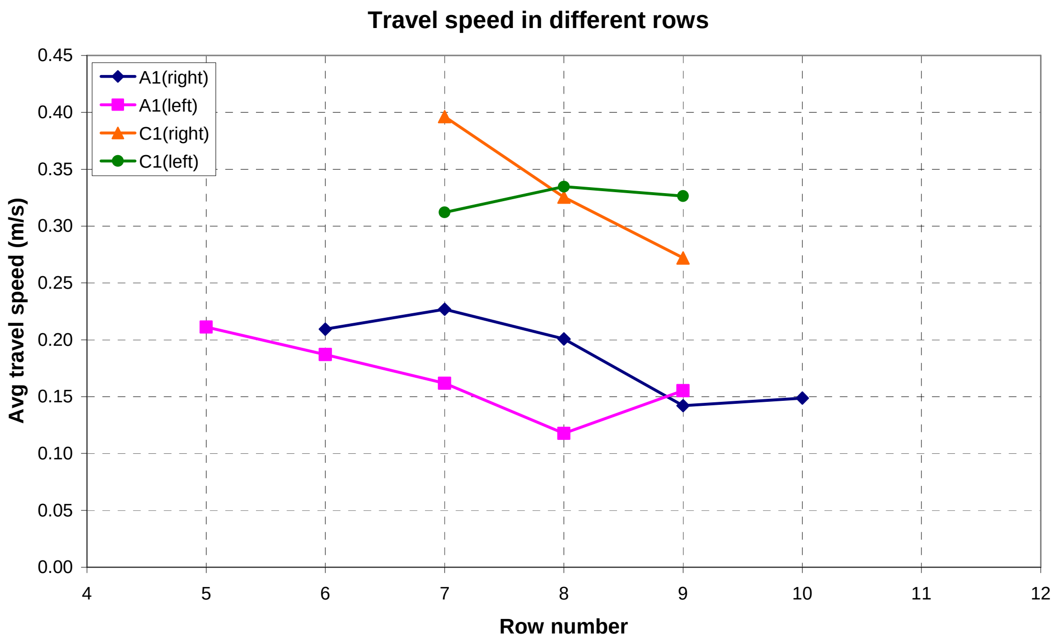


Figure 5.24: Travel speed in different rows

S4 is a different case as the view of the camera only contains the area at doorway. The initial position of people who passed through can not be specified. Ten people are randomly selected from the footage at every interval of ten seconds throughout entire evacuation process. The average value of travel speed is 0.4m/s, which is higher than A1 and C1. This is not only because occupant density is different, but also the floor of the designated area is flat, resulting in different moving behaviour. Thus, this data should not be put together with A1 and C1 in further discussion.

6 Data Analysis and New Relationship

The data obtained from the evacuation drills is processed in order to extract a new relationship between flow rate and occupant density, particularly for lecture theatre rooms. Accordingly, a calculation method of evacuation time applying the new relationship will be presented. The variables, occupant density of lecture room, occupant density of aisle, travel speed, door width, corridor width and flow rate, are mainly discussed in this chapter. This new method will be not only compared with experimental data, but also compared with other methods from different researches or literatures.

6.1 Experiment Result

The experiment result is extracted from original data recorded in PSION. As the number of people was counted from visual observation, a certain degree of miscounting is unavoidable. However, the error is supposed to be in a very low magnitude because the recorders had been trained and their position was very close to each exit at the time.

Table 6.1 shows the recorded data for each exit. The evacuation time in the experiment is defined as the time from the alarm activation to the evacuation of the last person. For those lecture rooms where exits are located at front and back, the last person was mainly evacuated from the front entrance from which the majority of the population chose to exit the room. There are a few exceptional cases as there is a replaced exit at mid-way along sidewall in these rooms resulting in more usage. The reason is explained in previous section.

Table 6.1: Experiment Result

Lecture Room	Egress Route	No. of People	Evacuation Time(s)	Flow Rate (ppl/s)
A1	Front Entrance	105	111	1.06
	Side Exit	78	114	0.81
	Back Exit	63	96	0.84
	Total	**246**	**114**	**2.71**
A2	Front Entrance	122	101	1.41
	Back Exit	49	97	0.59
	Total	**171**	**101**	**2.00**
A3	Front Entrance	95	84	1.66
	Back Exit	1	36	N/A
	Total	**96**	**84**	**1.66**
C1	Front Left Entrance	66	98	1.02
	Front Right Entrance	54	73	1.08
	Back Left Exit	38	89	0.66
	Back Right Exit	34	88	0.56
	Total	**192**	**98**	**3.32**
C2	Front Entrance	155	117	1.68
	Back Exit	31	88	0.41
	Total	**186**	**117**	**2.09**
C3	Front Entrance	53	73	1.18
	Back Exit	8	44	0.4
	Total	**61**	**73**	**1.58**
S2	Front Entrance	56	77	1.12
	Back Exit	44	76	0.74
	Total	**100**	**77**	**1.86**
S4	Front Entrance	63	77	1.15
	Back Exit	63	91	0.89
	Total	**126**	**91**	**2.04**

The flow rate in the last column is derived from the correlation between the cumulative number of evacuated people and the travel time. Figure 6.1 is an example of scatter plot for A1. The linear trend-line gives a function of y = ax + b. Coefficient “a” can be physically interpreted as the number of people passing through an exit in unit time, which is termed flow rate expressed in persons/second. This coefficient directly reflects how fast people egress from each exit. All of the flow rates in other lecture rooms are obtained by this approach as shown in Appendix D. It is confident to apply this method as the accuracy of linear regression is in relative high level with the average coefficient of determination ($\mathbf{R}^2$) of 0.975.

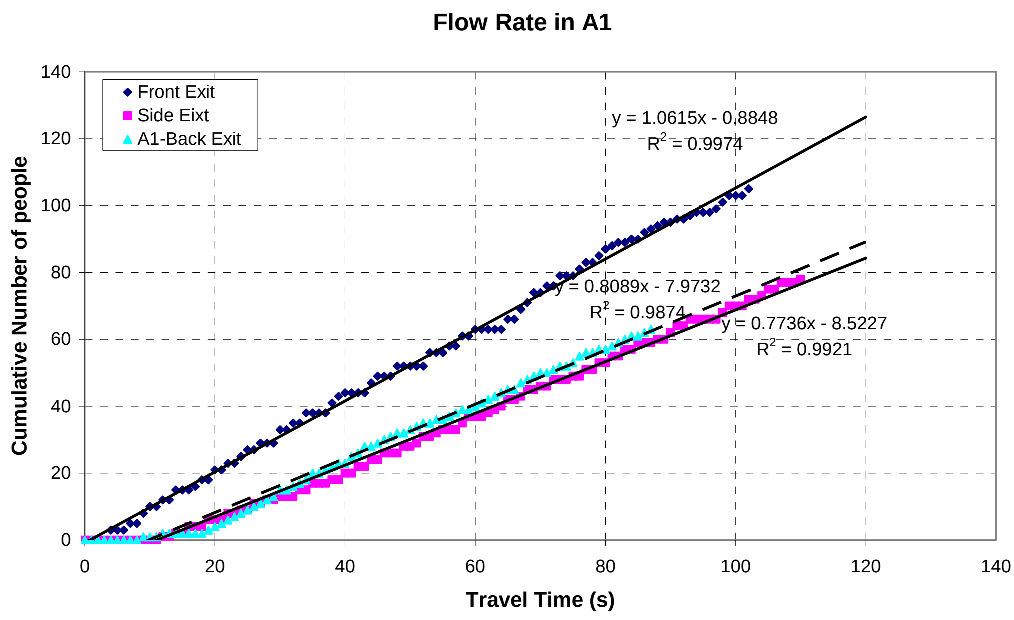


Figure 6.1: Flow rate in A1

Instead of evacuation time, the travel time is applied in this chapter by subtracting the pre-movement time in order to find out how population density affects crowd movement after the decision making phase. An assumption is made that a specific value is adopted as pre-movement instead of a distribution due to the difficulty of data collection. In addition, the specific pre-movement time of A2, A3, C2, C3, S2 and S4 is assumed to be the average value from A1 and C1 because of the absence of completed video records. This assumption may potentially affect the results in further analysis. More research is suggested to figure out the magnitude of influence to the results caused by this assumption.

6.2 Correlations of relevant variables

In order to investigate the factors that impact on the duration of the movement in lecture rooms, typical features for lecture theatre rooms need to be specified. In terms of geometry features, the variables are:

- Length of the room
- Width of the room
- Width of the row
- Slope of the aisle
- Width of the aisle
- Width of the door
- Location of the door

In terms of the occupant characters, only occupant population in lecture rooms is concerned in this case as the dominant population in lecture rooms during the experiment was formed by students with regular evacuation practice. The distribution of occupants in the room can be an issue while the class has very low attendance. More experiments need to be carried out for further analysis in this area.

The length and width of the room can be incorporated to an integrated variable, occupant density, expressed by persons/m^2. It is more explicit to conduct analysis with this variable regarding travel time.

Generally, the width of each row in the seating area is an important factor which directly determines how fast people can move along the seats in row. However, it turns out to be relatively insignificant if the lecture theatres have a high occupancy as the stream will be congested in aisle at the beginning of evacuation process with most of people waiting at their seat. This is well explained from video observation. Thus, this variable is not in discussion.

The slope of aisles could be an interesting issue because it does not only affect people's movement along aisle, but also might effect on people's decision of egress route choice. People might decide to go downwards, along the sloped aisle, to an exit far away in the front rather than climb upward to an exit much closer at the back. Their decision could be changed as a result of a flat aisle in the room. Due to the lack of diverse geometry in the experiments, any further exploration of this question is not possible.

As the potentially narrowest point in the room, the widths of door and aisle variables determining the location of any queuing. This is based on a bottleneck concept that severest congestion will take place at the narrowest point along the passageway. The comparison between these two variables gives a reference in order to decide which width should be adopted in the new relationship.

The location of exits, especially for alternative exits, is another factor which could affect people's egress choice. This is discussed in a previous chapter. The quantitative analysis requires more data in terms of different exit's location.

On summary, the variables in following discussion are:

- Number of occupants
- Occupant density
- Width of door
- Width of aisle

In order to investigate relationships among the variables, correlation analysis is introduced. This is a statistical measure which indicates the degree to which one variable changes with another variable. The value of correlation is always between -1 and +1 giving the strength of association between two variables (McEwen, 1995). Figure 6.2 shows the correlation between travel time and four selected variables from the lecture rooms in the experiment. The calculation procedure is described in Appendix E.

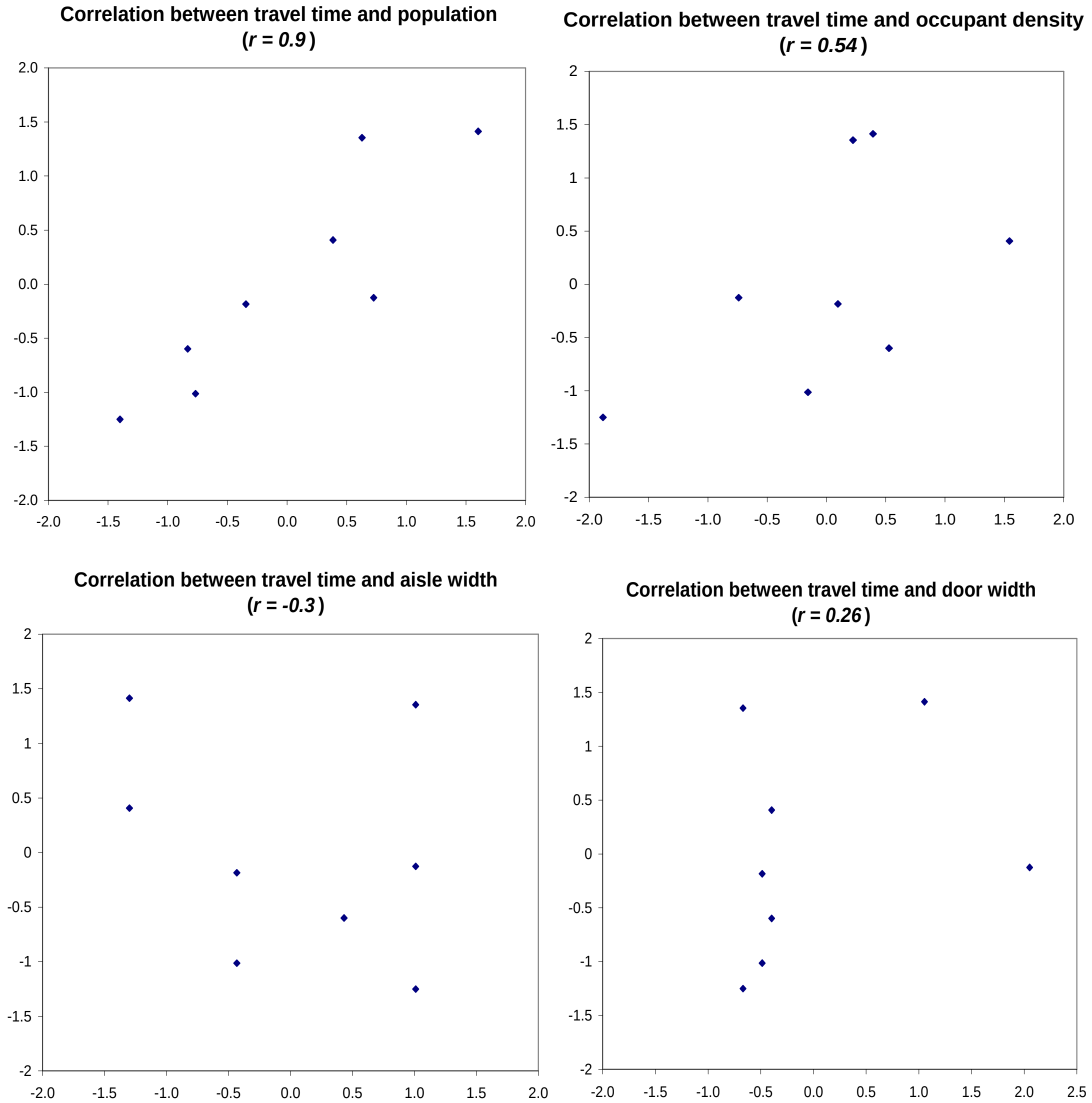


Figure 6.2: Correlation between travel time and selected variables

According to the calculation results, the number of people has a strong positive association with travel time due to the correlation coefficient of 0.9. Obviously, more occupant load results in longer queuing time and movement time. Consequently, the occupant load in buildings is strictly standardized for provision of evacuation design. Therefore, the occupant load should be included in new relationship.

For other variables, generally, the correlations do not show strong association with travel time. This might be due to the shortage of experimental data. Usually, uncertainty appears in data processing if a minor amount of data is presented. But still, there is an implicit trend that the occupant density has a positive relationship with the travel time as “r” equals to 0.54. In general understanding, both widths of the aisle and the door should have a negative correlation with travel time. Thus, the correlation for the aisle width appears a negative value of -0.3. The uncertainty of data in this case plays an important role in the results.

In order to investigate the relationship of each variable further, another dependent variable, flow rate, is selected for correlations instead of travel time. The new variable has more advantages for analysis as it directly reflects the speed of evacuation process with a relationship of Travel Time = Occupant Load / Flow Rate.

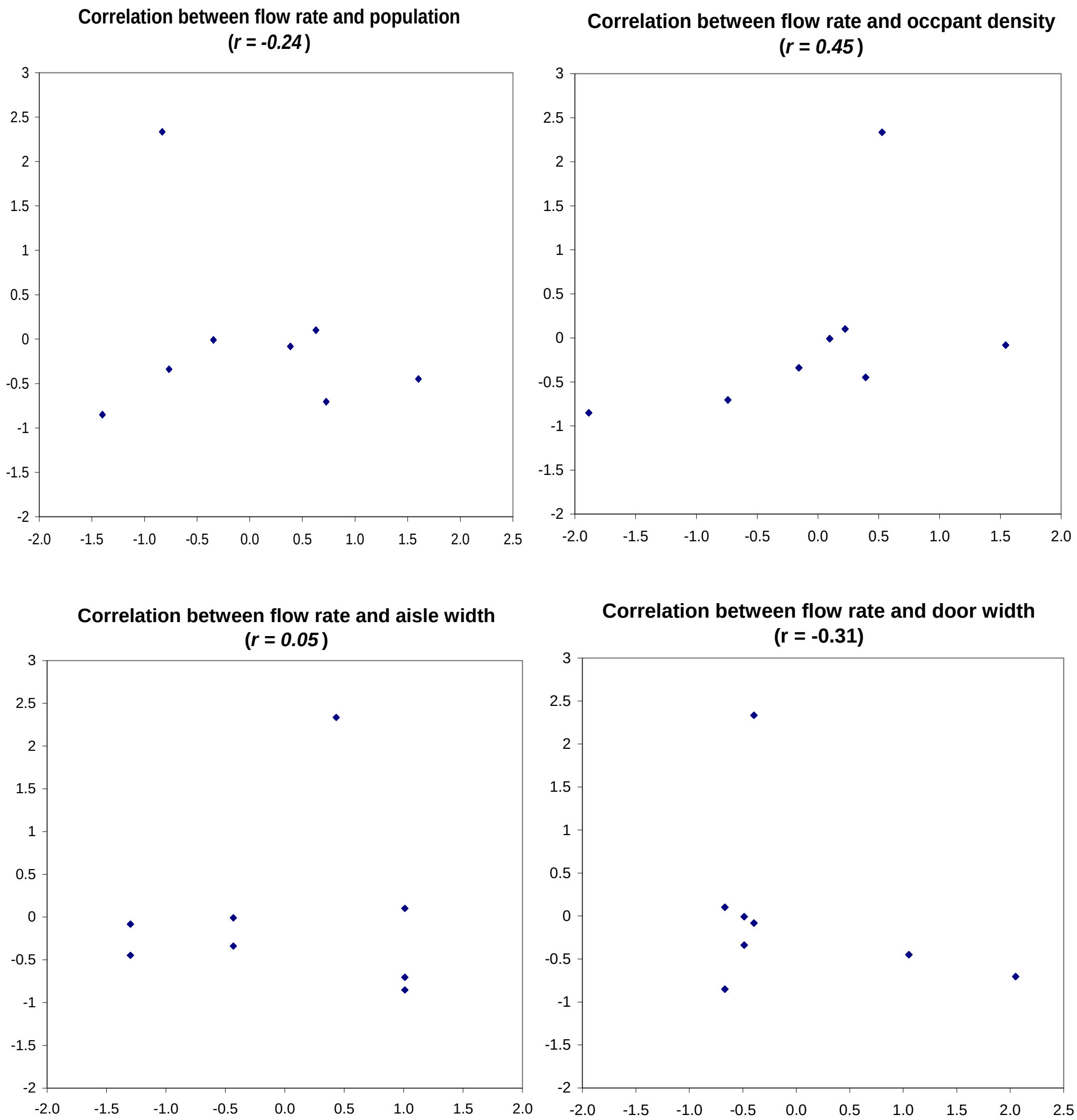


Figure 6.3: Correlations between flow rate and selected variables

Figure 6.3 gives the correlations between flow rate and four selected variables. Again, imperfect correlations imply that results cannot universally represent general situations. Compared with the correlation obtained from the travel time (See Table 6.2), only occupant density has a consistent relationship with both dependent variables. Thus, the occupant density is a more reliable variable that will be further investigated for development of the new relationship.

Table 6.2: Comparison of correlations from two dependent variables

Variables	Correlation from Travel Time	Correlations from Flow Rate
Population	0.9	-0.24
Occupant Density	**0.54**	**0.45**
Aisle Width	-0.3	0.05
Door Width	0.26	-0.31

6.3 Queuing Density

In terms of the characteristics of lecture theatre rooms, people's movement is confined by fixed seats arranged in rows, which differs from other type of rooms where people are able to walk toward the exit straightaway. Instead, central aisles are intensively occupied by people instantly at the very beginning stage of egress. Consequently, the density of central aisle area turns out to be a more crucial parameter determining people's movement. As this density specifies the configuration of the area where most queuing occurs in lecture theatre, it is quoted as "queuing density". Logically, this local density would be expected to have a positive correlation to room density. This correlation is expected to be incorporated in the new relationship for travel time prediction.

From previous chapter, the queuing density was obtained from video observation in A1, C1 and S4. Although there are only three experimental data, a trandline can still be plotted giving a prediction within a range of room density.

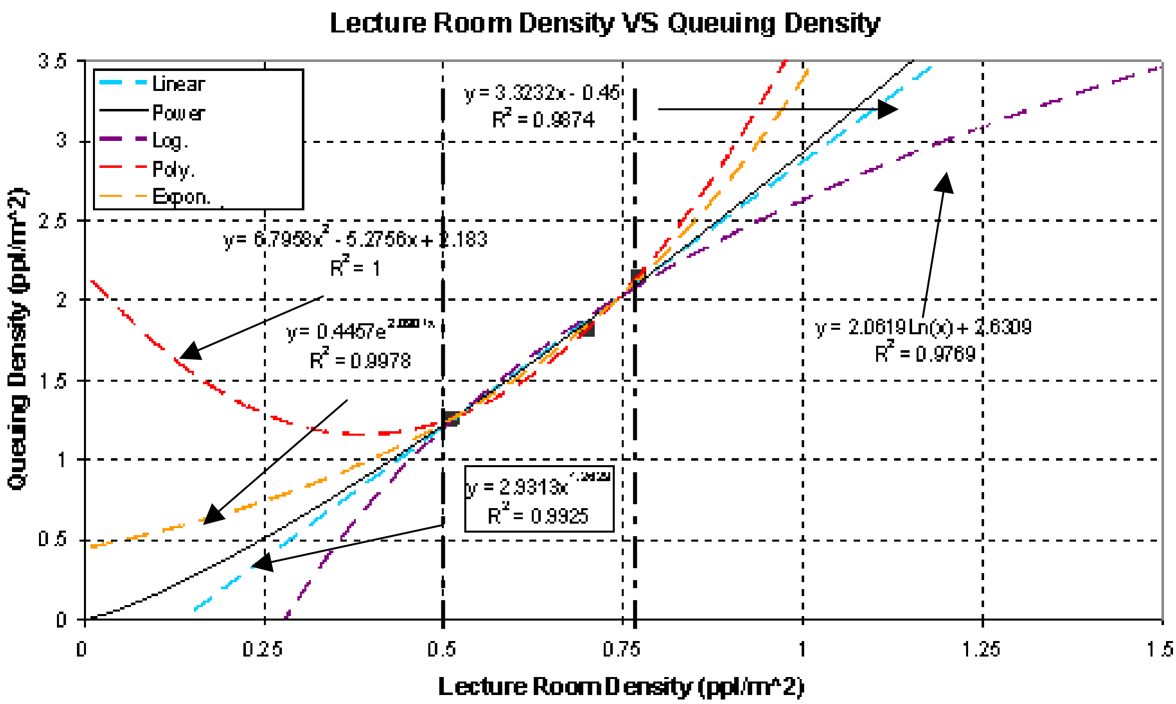


Figure 6.4: Correlation between lecture room density and queuing density

Figure 6.4 shows five different types of regression lines based on limited data points. Within the range from 0.51ppl/m^2 to 0.77ppl/m^2, all of these five regressions are very close to the data points. Power and exponential regressions give a higher accuracy with R^2 of 0.9925 and 0.9978 and polynomial regression matches the data perfectly. When the range turns back to 0~0.55ppl/m^2, the difference is obvious. Except for power trandline, rest regression lines cross either X axis or Y axis. From practical point of view, queuing density relies on room density and they should coexist at same time. In general, it is very abnormal that an entire population could skip over the aisle to the exit unless it is in extremely urgent situations. Only the power regression reasonably presents the relation between two densities. Therefore, this regression is applied for further analysis of new relationship. However, this regression is not the only option. Further research should be conducted in order to obtain a better relation based on more data.

$$D_{queuing} = 2.93 \times D_{lecture\ room}^{1.26}$$ **Equation 6.1**

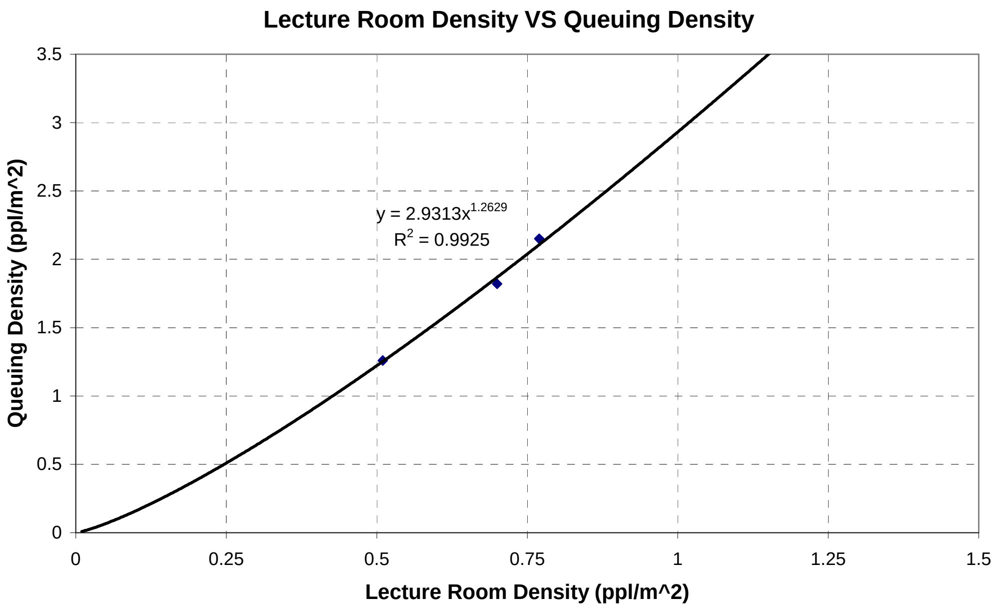


Figure 6.5: Power regression between queuing and room density

6.4 Method to Obtain the New Relationship

From previous discussion, flow rate and queuing density are two major variables which will form the new relationship. In order to achieve the objective, two approaches are investigated in this chapter.

6.4.1 Method One: Queuing Density VS Flow Rate

To obtain the relationship, one approach is to find out the experimental correlation between queuing density and flow rate directly based on data plots.

Applying the correlation in Equation 6.1, the queuing density in all other lecture rooms can be calculated from their room densities. On the other hand, the flow rate is derived from the experiment data for each exit. In order to reduce the influence from the variables of door width and aisle width, a new variable, specific flow, is introduced in the analysis. This is the flow of the number of people passing a congestion point in a unit time through a unit effective width, expressed in persons/s/m (Nelson and Mowrer, 2002). The effective width, used as the narrowest point along the egress route, is obtained from the comparison between door width and aisle width. If the main entrance is located at both sides of the lecture room corresponding to an aisle, there will be two separated egress routes with a main entrance. The narrower width should be adopted in the calculation. However, there are lecture rooms where the door width is applied even through it is wider than the aisle width, as there is only one main entrance but two or more aisles for the whole room. Queuing still takes place in aisle area, but there will be a severer congestion at the doorway after flows from each aisle merge together. Figure6.6 is a sketch giving visual illustration.

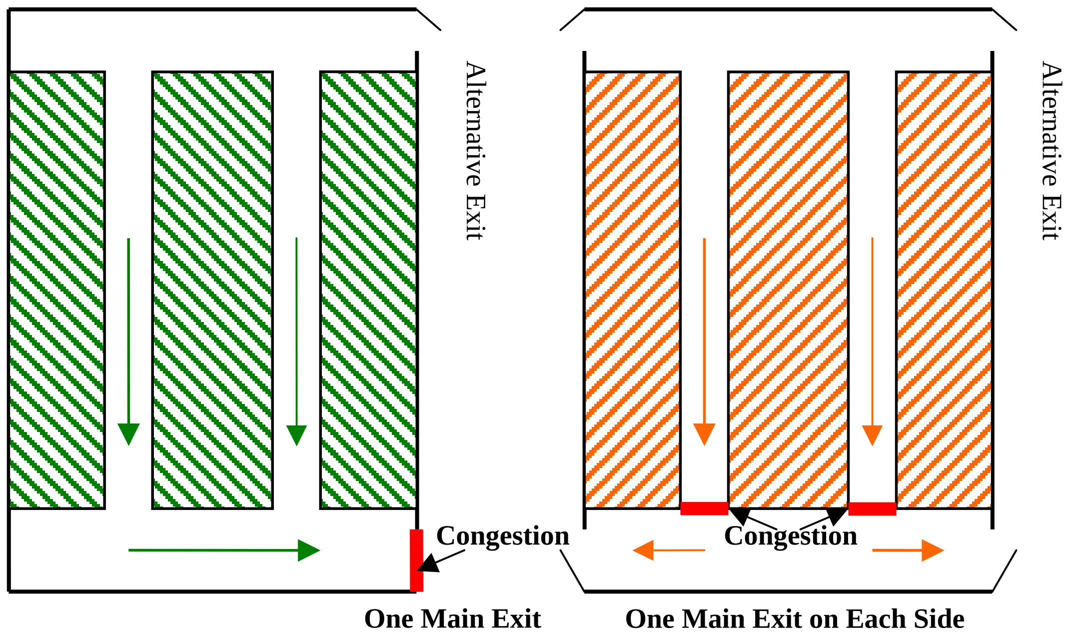


Figure 6.6: Sketch of the lecture rooms with different congestion point

As the specific flow derived from experiment data is for each exit, in order to get a general specific flow corresponding to a queuing density for the whole lecture room, a weighted average specific flow is calculated in favour of the percentage of occupant choosing each exit. It is appropriate to use this weighted average value rather than simply take the mean value of each exit.

For example,

Lecture A1:

Main entrance: Choice = 42.7%, Specific flow = 0.88 ppl/s/m

Side exit: Choice = 31.7%, Specific flow = 0.68 ppl/s/m

Back exit: Choice = 25.6%, Specific flow = 1.12 ppl/s/m

$$Weighted\ average\ Specific\ \ flow = \frac{F_{main} \times 42.7\% + F_{side} \times 31.7\% + F_{back} \times 25.6\%}{100\%}$$

Figure 6.7 is the correlation between queuing density and specific flow. The processed data is scattered around within a wide range that a regression can hardly be used to present the relation. The best-fitting polynomial trendline gives a poor estimation with R^2 of 0.41, which is not accurate enough for prediction of travel time. This might be due to the insufficient volume of available data or some complicated errors contained during the experiment, therefore, a new relationship is difficult to achieve by the first method.

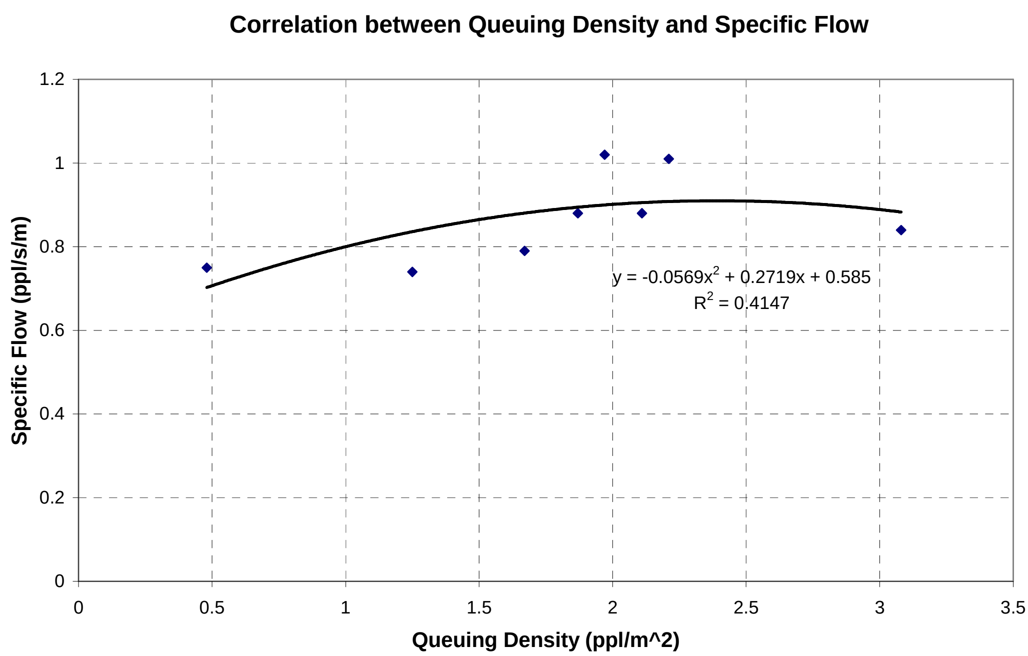


Figure 6.7: Correlation between queuing density and specific flow

6.4.2 Method Two: Queuing density VS Travel Speed

From the definition of specific flow, another factor affecting it is the travel speed at the exit point. By taking queuing density into account, the specific flow can be expressed as the product of two variables, travel speed and queuing density (Nelson and Mowrer, 2002). The new relationship can be achieved if the travel speed, determined by occupant density, is specified from experiment data. Two sets of speed data obtained from video observation in A1 and C1 (See Table 5.4), in fact, is the average moving speed of the entire group rather than the instantaneous speed at exit point. Also, there are only two available data sets which make it hard to give an appropriate description of the relation with queuing density. Therefore, this relation has to be described in an alternative way using other information from the experiment.

In terms of evacuation drill in each lecture room, when people pass through exit point, new people join in the flow making the queuing density relatively constant. Based on this point, it can be assumed that at the beginning of evacuation process, the population using each egress route forms a long queuing area with an effective width, either the door width or aisle width, and moving through the exit point at the same speed. As the queuing density can be applied in this long-queuing area and the number of people is known, the length of the queue can be calculated. Also, the travel time for the population using each exit to egress out from the room was tested during the experiment as well. Thus, the speed can be obtained by dividing the length of queuing area by travel time. Averaging this speed from each exit in favour of the percentage of people choosing that exit, the weighted average speed is the average moving speed of the whole population in the room when they are passing the exit point, which gives an overall description of how fast the evacuation is proceeding. However, this assumption might be not very accurate if a low occupant density is presented as it leads to an inconsistent queuing density.

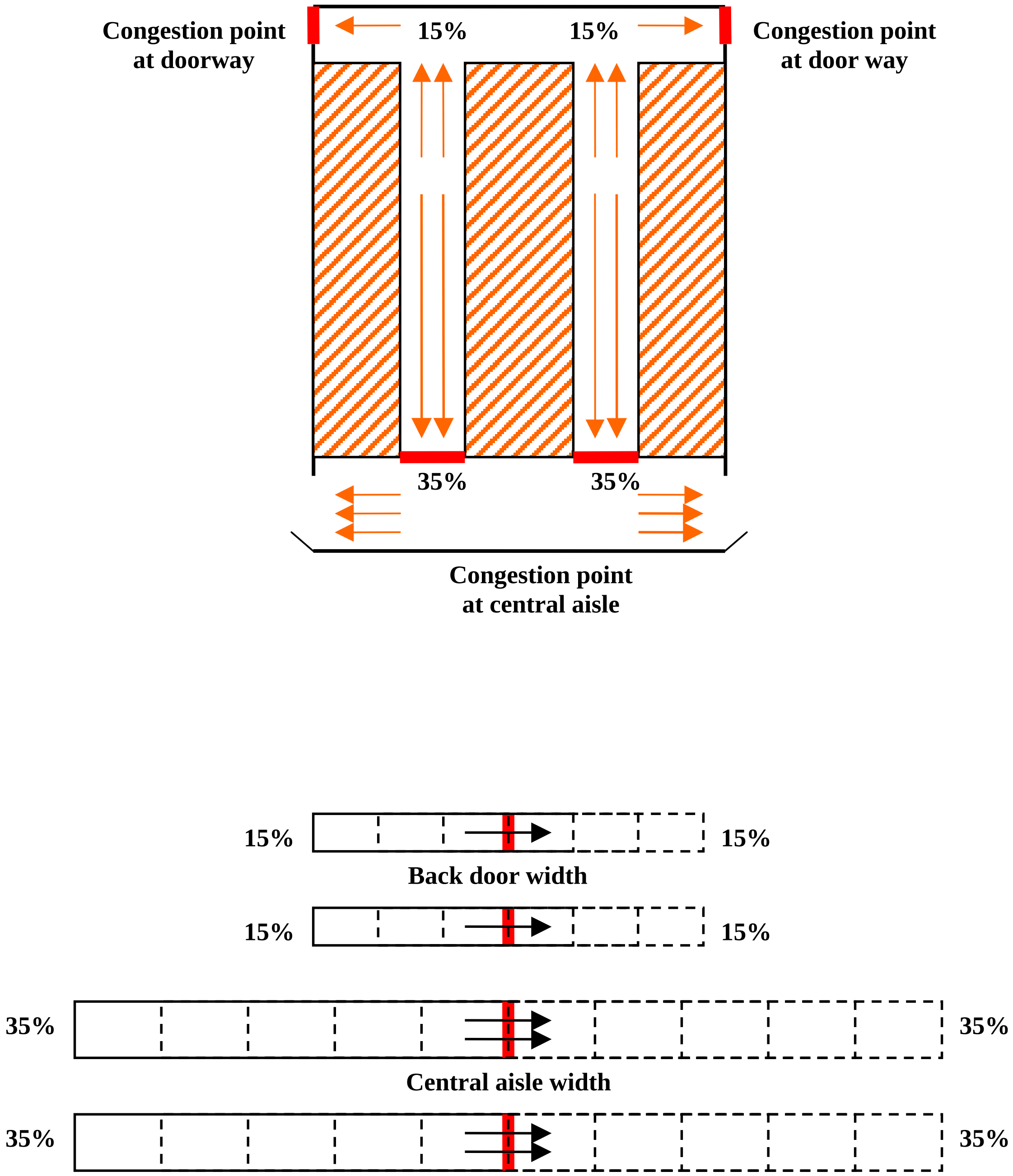


Figure 6.8: Sketch of new method to calculate travel speed

Figure 6.8 gives a demonstration of this approach. There are four egress routes in the lecture room and the percentage of people who chose each exit is given. Assume that the occupant load and travel time for each exit are known and the queuing density also can be specified from room density using Equation 6.1. The overall travel speed can be calculated as:

For two front egress routes:

1. As door width > aisle width, effective width = aisle width.
2. Queuing area = number of people × 35% / $D_{queuing}$
3. Length of the “queue” = queuing area / aisle width
4. Travel speed = Length of the “queue” / travel time

The same procedure applies for the two back egress routes but using door width instead as it is narrower than aisle width. In the end, the weighted average speed for whole room is calculated as:

$$Weighted\ average\ speed = \frac{(Speed_{front} \times 35\% + Speed_{back} \times 15\%) \times 2}{100\%}$$

By applying this approach, the travel speed of each lecture room in the experiment is calculated and the results are shown in Table6.3.

Table 6.3: Calculation of travel speed

Location	Number of people	Exit Choice %	Room Density (ppl/m^2)	Queuing Density (ppl/m^2)	Door Width (m)	Aisle Width (m)	Travel speed (m/s)	Weighted average speed(m/s)
A1(Main)	105	42.7	0.77	2.11	1.65	1.2	0.43	0.40
A1(side)	78	31.7			1.65	1.2	0.38	
A1(Back)	63	25.6			0.75	1.2	0.40	
A2(Front)	122	71.3	1.04	3.08	1.65	1.2	0.29	0.28
A2(Back)	49	28.7			0.75	1.2	0.27	
A3(Front)	95	99.0	0.80	2.21	1.65	1.8	0.39	0.39
A3(Back)	1	1.0			0.75	2	-	
C1(Front Right)	66	34.4	0.51	1.25	1.5	2	0.46	0.53
C1(Front Left)	54	28.1			1.5	2	0.56	
C1(Back Right)	38	19.8			0.75	2	0.60	
C1(Back Left)	34	17.7			0.75	2	0.55	
C2(Front)	155	83.3	0.73	1.97	1.5	2	0.53	0.49
C2(Back)	31	16.7			0.75	2	0.30	
C3(Front)	53	86.9	0.24	0.48	1.5	2	1.33	1.33
C3(Back)	8	13.1			0.75	2	-	
S2(Front)	56	56.0	0.64	1.67	1.4	1.5	0.41	0.44
S2(Back)	44	44.0			0.95	1.5	0.48	
S4(Front)	63	50.0	0.70	1.87	1.4	1.5	0.41	0.45
S4(Back)	63	50.0			0.95	1.5	0.49	

From the result, the predicted speed is generally higher than the data obtained from observation in A1 and C1. This speed is more applicable from a design point of view as it gives a general estimation throughout the entire evacuation procedure. According to the prediction of queuing density, Lecture C3 has a very low queuing density of $0.48ppl/m^2$, which is out of the range where occupant density interacts with travel speed ($0.56ppl/\ m^2 \sim 3.8ppl/\ m^2$), suggested in SFPE handbook. It means people's movement is controlled by their mobility rather than occupant density in C3. Therefore, the calculated speed is expected to overestimate the real situation. A suggested travel speed of 1.2m/s (Buchanan, 2001) should be applied in this case. The correlation between queuing density and travel speed is shown in Figure 6.9.

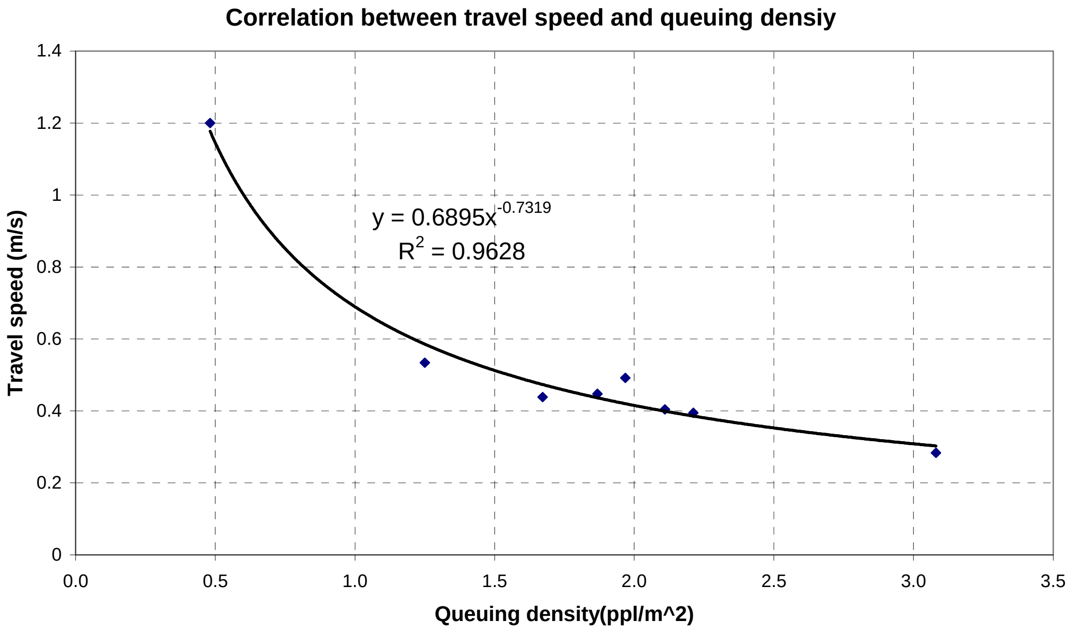


Figure 6.9: Correlation between queuing density and travel speed

In the graph, two variables demonstrate an agreement with a power regression in the range from about 0.5ppl/m^2 to 3.0ppl.m^2. The accuracy of the regression is in a relatively high level with R^2 of 0.9628. Thus, the equation of the regression can be applied for prediction of travel speed. Due to the lack of data, more data should be obtained from experiments in order to improve this equation for confidence.

$$Travel\ speed = 0.69 \times D_{queuing}{}^{-0.73} \qquad \textbf{Equation 6.2}$$

So far, the specific flow is able to be achieved from the product of travel speed and queuing density. Accordingly, the travel time can be predicted by applying this method.

6.4.3 Summary of the new relationship for prediction of travel time

Concluding previous analysis, the travel speed can be expressed with a single variable, occupant density of lecture room, by substituting Equation 6.1 to Equation 6.2. Then the specific flow and travel time can be accordingly expressed with this density.

$$Travel\ speed = 0.69 \times (2.93 \times D_{room}{}^{1.26})^{-0.73} = 0.315 \times D_{room}{}^{-0.92} \quad \textbf{Equation 6.3}$$

$$Specific\ \ flow = 0.315 \times D_{room}{}^{-0.92} \times D_{queuing}$$
$$= 0.315 \times D_{room}{}^{-0.92} \times 2.93 \times D_{room}{}^{1.26} \quad \textbf{Equation 6.4}$$
$$= 0.92 \times D_{room}{}^{0.34}$$

$$t_{move} = \frac{Number\ \ of\ \ people}{specific\ \ flow \times congestion\ \ width} = 1.1 \times N \times D_{room}{}^{-0.34} \times w_{congestion} \quad \textbf{Equation 6.5}$$

Equation 6.5 is the final version of a new relationship particularly for lecture theatre type of room. It gives an alternative method to predict evacuation time when design buildings contain lecture room or theatres. Three necessary parameters are required for this method:

- Occupant load (N)
- Geometry of the room (Length & Width)
- Door width & aisle width

The method is also based on the following assumptions:

- Population does not include disabled people, mainly formed by young people.
- Pre-movement time in other lecture rooms is the average value from A1 and C1.
- Travel speed of individuals and density at congestion point are constant during the evacuation process.

6.5 Prediction of new method

By applying this new relationship to all lecture rooms in the experiment, the evacuation time is calculated as the sum of the longest travel time among the exits of each room and the designated pre-movement time (See Appendix F). The result comes up with a relatively small error of 4.77% averaged in terms of prediction of evacuation time. This proves that the correlation used for predicting queuing density in Section 6.3 is reasonably appropriate and the assumption made to achieve travel speed is acceptable in the range of occupant density from the experiment. (See Figure 6.10) As the new relationship is derived from the experiment data, availability should be verified by extracting data from other research or doing another set of experiments. Three cases acquired from different sources are addressed in order to present the verification.

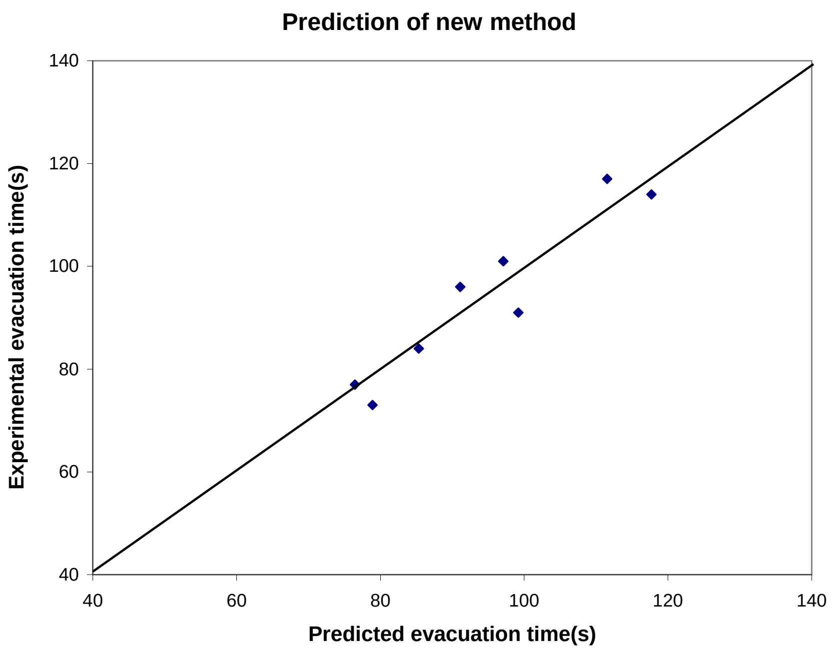


Figure 6.10: Prediction of new method on all lecture rooms in the experiment

6.5.1 Case 1: Experiment data from E17

The experiment was a part of research during the Human Behaviour block course, carried out in Lecture E17, Engineering Building, on the campus of Canterbury University. During the experiment, there were 27 students in total and they were informed to get involved in the experiment. The evacuation time was counted at the moment when all students were ordered to start moving without decision making, which means the pre-movement does not apply in this drill.

In terms of the geometry of E17, it is 7.85m long by 5.18m wide with an area of about $40m^2$. Only one egress route was available with the door width of 0.75m and the aisle width of 0.6m. Figure 6.11 is the layout of E17. From the experiment, it took 28 seconds for 27 students to evacuate from E17.

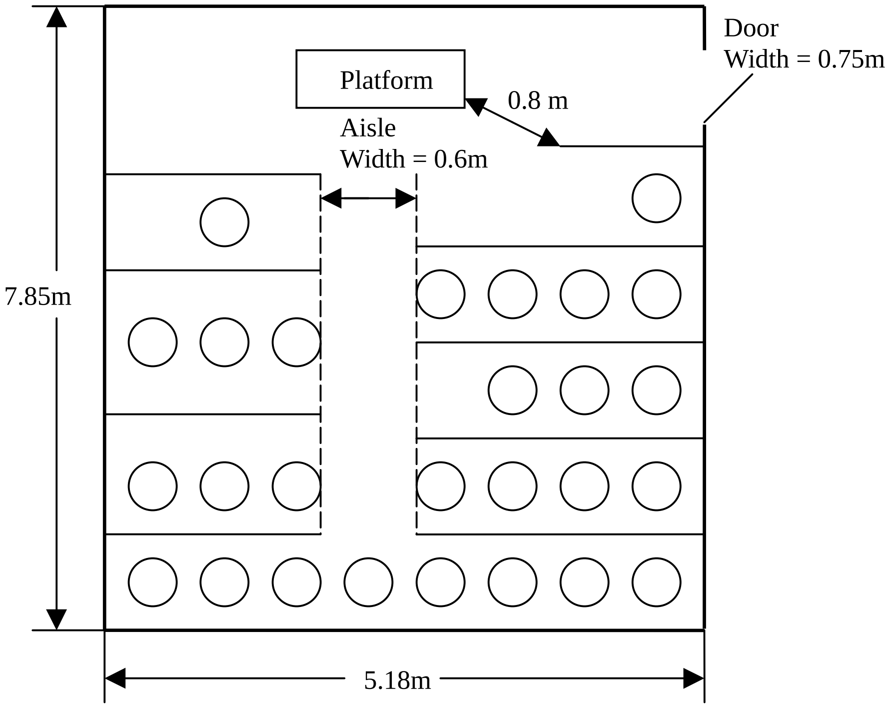


Figure 6.11: Geometry of E17 and position of occupants

Applying the parameter in the new relationship, the result comes up with a evacuation time of 45s, which is over 60% overestimation. (See Appendix F)

Comparing with the size of lecture rooms used for analysis in the new relationship, E17 is too small to make comparison. The relationship between queuing density and room density might be changed if the number of rows is below a certain level decreasing flow merging.

Also, the people involved in the experiment had known the procedure in detail before it carried out. They might change their movement behaviour unconsciously (e.g. move faster, follow others closer) leading to the shorter evacuation time.

Another issue is that people were moving on the flat floor in E17. The travel speed is believed to be faster than that moving on sloped aisle.

Accounting for all of the different set up, it can be concluded that the new relationship can not give a reasonably accurate prediction for small-sized lecture room.

6.5.2 Case 2: Experiment data from Ko (2003)

Another set of experimental data of an evacuation trial in lecture room was summarized from Ko's thesis (Ko, 2003). The actual experiment was originally reported by Kimura and Sime in 1989 and Sime in 1992. There were two trials conducted in the same lecture room but with different situation and time. In the first trial, "Study 1", 56 students were involved in the trial but they were not informed and had no evacuation practice. Also, most of them had never been in an evacuation drill before. Very poor instructions were given by the lecturer during the evacuation process. On contrary, in the second trial, "Study 2", a different group of 63 students was selected and the evacuation was announced before the alarm was raised and effective instructions were given as well.

In terms of the building geometry, the room is 8.56m wide by 10.47m long. There are two egress routes along each side, one with main entrance (0.8m wide) and the other route with a fire exit (0.76m wide). The floor in the room gradually declines from back to front. The effective width of aisle at each side is 0.65m and 0.85m respectively. Figure 6.12 shows the layout of the room.

The results give quite different evacuation times between the two trials. In Study 1, 55% of occupants chose the main entrance as the egress route whereas 45% of occupants chose the fire exit. The total evacuation time was 181s. In Study 2, much shorter evacuation time was obtained with only 88s. In this case, 62% of occupants chose main entrance instead and 38% chose fire exit. Table 6.4 gives the chronological events in Study 1 and 2.

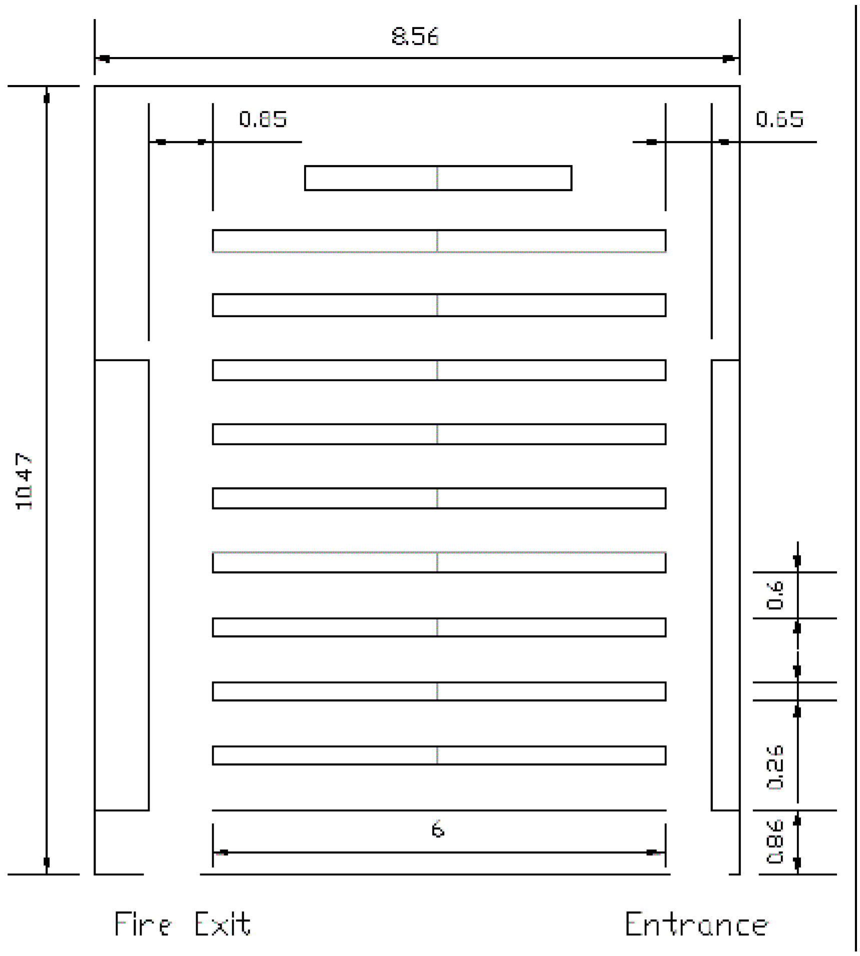


Figure 6.12: The layout of the lecture room in Study 1&2 (From Ko, 2003)

Table 6.4: Chronological events of the evacuation trials (mins:secs)   (From Ko, 2003)

Theatre	Entrance First	Entrance Last	Time Span	N	Fire Exit First	Fire Exit Last	Time Span	N
Study 1	0:47	2:54	2:07	31 (55%)	1:35	3:01	1:26	25 (45%)
Study 2	0:17	1:28	1:11	39 (62%)	0:21	1:15	0:54	24 (38%)

As there is no detailed information about pre-movement time in the two trials, the time for the first person to approach the main entrance is regarded as the general pre-movement time for whole population. Applying the new method to these two cases, the result is 108s for Study 1 and 92s for Study 2. (See Appendix F)

The result does not match the experiment data in Study 1, with a difference of 40.41% underestimation. The assumption made for pre-movement time may cause the inaccuracy. More importantly, the new method is based on the experiment data, from which most of occupants are familiar with the procedure of evacuation practice and effective direction from the lecturer is given. The unfamiliarity of the occupants and poor direction in Study 1 made a long evacuation time. Therefore, the condition in Study 1 is not very suitable for the application of the new method.

On the other hand, the predicted evacuation time for Study 2 is quite close to the actual experimental data with only 4.93% overestimation. Announcement of evacuation practice made a much shorter pre-movement time and corresponding evacuation time. Although this may change people's behaviour throughout the evacuation process, the announcement can be regarded as the compensation of unfamiliarity of evacuation practice as the group of students in Study 2 had not been trained before. Also good direction facilitates the evacuation's progress. Generally, the new method is applicable under the condition in Study 2.

6.5.3 Case 3: Experiment data from Weckman (1999)

Another evacuation exercise was arranged in a theatre, organized by the theatre staff in co-operation with the fire department and an insurance company (Weckman, Lehtimäki and Männikkö, 1999). This theatre was used for entertainment rather than education. During the exercise, occupants were also not informed of the evacuation beforehand. In total, there were 612 participants involved at the time the fire alarm was raised. They were assumed to be unfamiliar with the theatre. After the fire alarm was raised, instructions were given by the public announcement system.

Figure 6.13 is a plan of the auditorium area in the theatre. The room is approximately 29m wide by 20m long. Two 2.13 wide aisles are located at both ends of seat rows. The main entrance at the front on each side is 3m wide and several fire exits were installed. However, very few occupants were observed to use these exits during the evacuation, which can be neglected compared with the whole population. Thus, two egress routes passing the main entrance were provided for the majority to egress. Again, the floor of the auditorium declines towards the front so that the last row is 4m above the front row.

As the evacuation space and the number of people were relatively large, the result gave a long period of 218s. Table 6.5 gives the chronological events of the evacuation exercises.

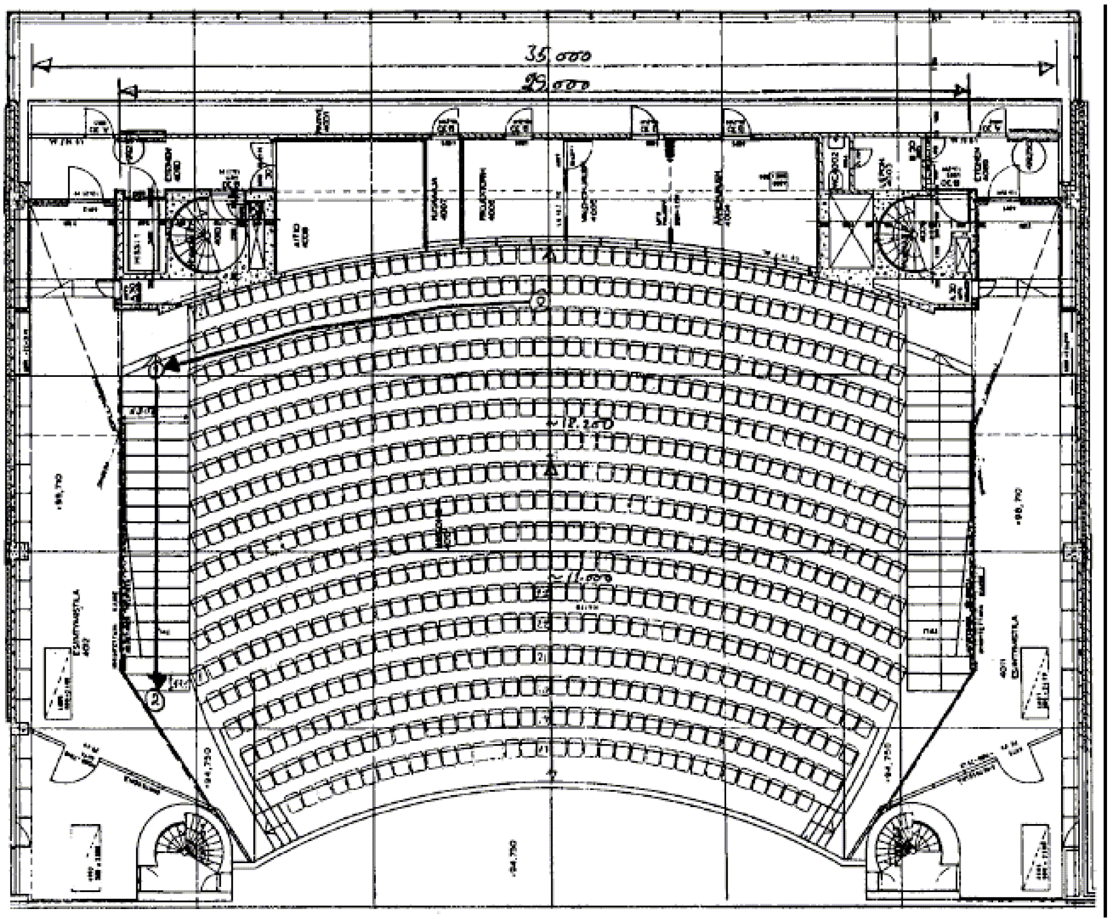


Figure 6.13: The auditorium of the theatre (From Weckman, Lehtimäki and Männikkö, 1999)

Table 6.5: Chronological events of the evacuation exercises (From Weckman, Lehtimäki and Männikkö, 1999)

Time (min:s)	Event
0:00	The fire alarm button was pressed. The fire drop-curtain began to come down.
0:25	The audience began to applaud. The first person started to leave.
0:32	The fire drop-curtain was down.
0:30 ~ 0:47	Tens of people started to leave.
0:47	The first announcement was read over the announcement system
1:06	The second announcement was read.
1:10	The first person arrived at the ground floor.
3:37	The last person left the auditorium.

From the description in the report, the pre-movement time for the population was not clearly stated, but hundreds of occupants were observed to start moving after the first announcement. Based on this point, the pre-movement time is assumed to be the time when the second announcement was read. Due to the symmetrical geometry feature and high occupation in auditorium area, half population is used for the calculation.

The prediction from the new method is very close to the experimental data with only 4.22% difference. (See Appendix F) The agreement between predicted time and experimental data verifies that the new method is applicable for a large-size theatre room. Figure 6.14 shows the prediction of all three cases from the new method.

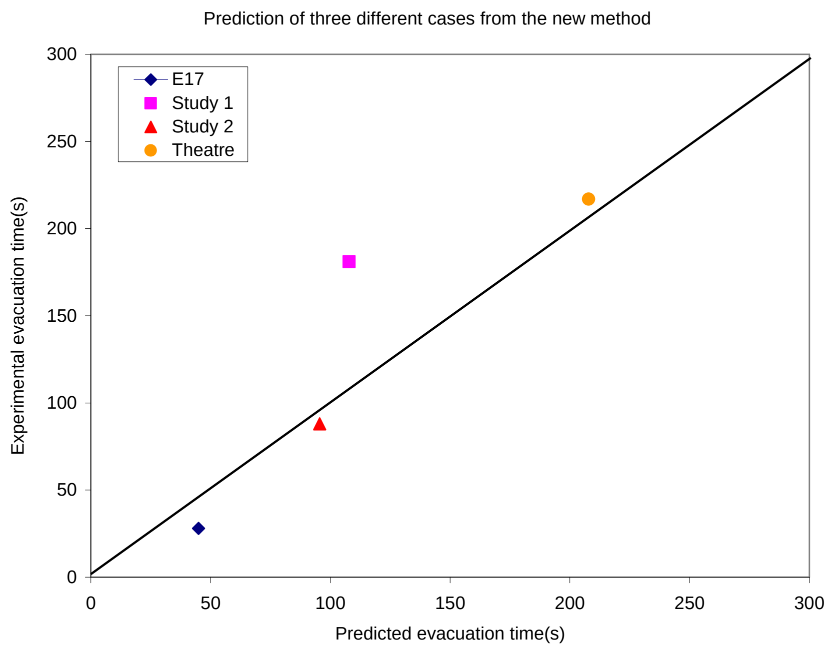


Figure 6.14: Prediction of the new method in three different cases

6.6 Comparison with other available methods

From previous work, a couple of relationships for crowd movement were derived from experimental data. As the experimental environment in each research varies in terms of the occupant type and geometric feature, each empirical equation gives a different prediction for the same evacuation process. In this section, four well known relations, introduced in Chapter 3, are used to calculate the evacuation time of the experiments conducted in this study and three cases extracted from other sources. With these results, a comparison with the new methods developed in this chapter is achieved. This is an approach to assess whether the new method gives a prediction as good as other well used calculation methods. The detailed calculation is shown in Appendix F.

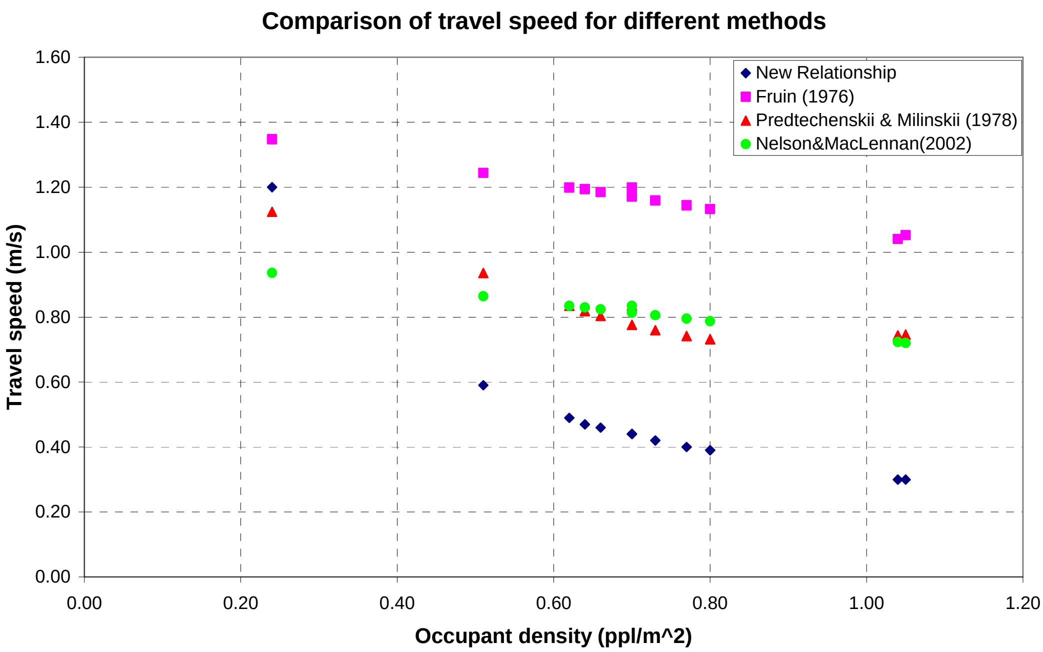


Figure 6.15: Comparison of predicted speed for different methods

In terms of travel speed, the new method gives the lowest estimation with an average of 0.49m/s. (See Figure 6.15) From the observation during the experiment in A1 and C1, the estimated walking speed of the crowd group is 0.2m/s and 0.33m/s respectively, which is slower the predicted speed. Compared with results from other methods, the new relationship gives the closest prediction. Fruin's method gives the highest average walking speed of 1.17m/s, which seems to be too far away from the observation. It is not reasonable that people could move more than 1 m/s in such a crowded room. Nelson & MacLennan and Predtechenslii & Milinskii give similar results around 0.8m/s in average, between the other two methods.

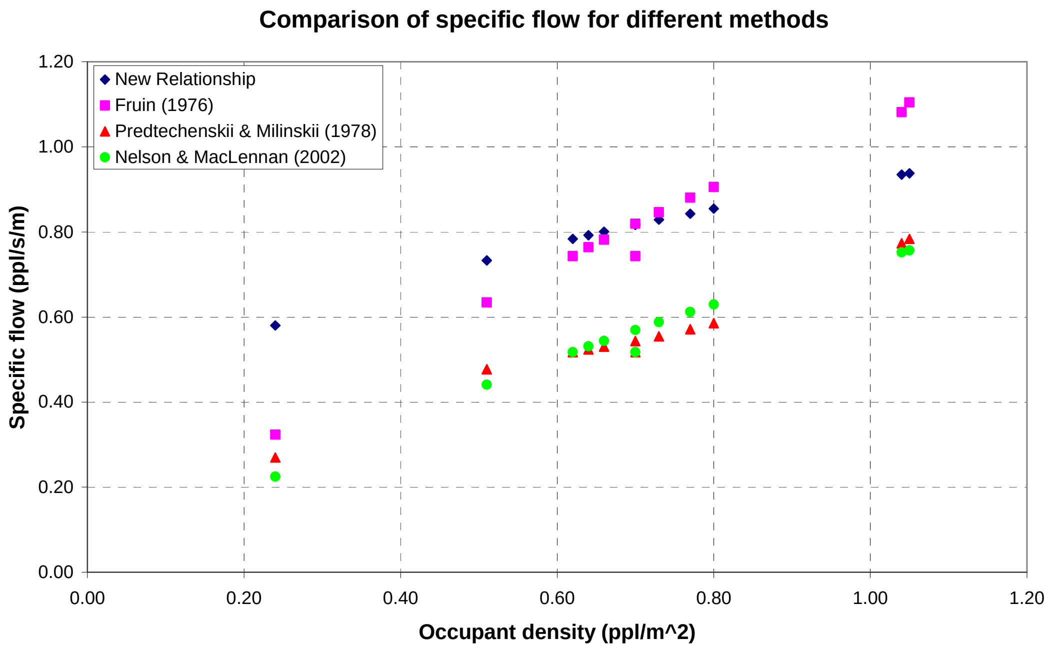


Figure 6.16: Comparison of specific flow for different methods

For the specific flow (See Figure 6.16), the prediction from Fruin's method is about 0.8 persons/s/m in average, which is quite close to the results from the new method. The other two methods give a lower prediction of 0.55 persons/s/m in average. As the density decreases, the predicted flow rate from the new method becomes relatively higher than the rest of the methods. In the range of high density up to 1 person/s/m, Fruin's method jumps up to the top of all methods.

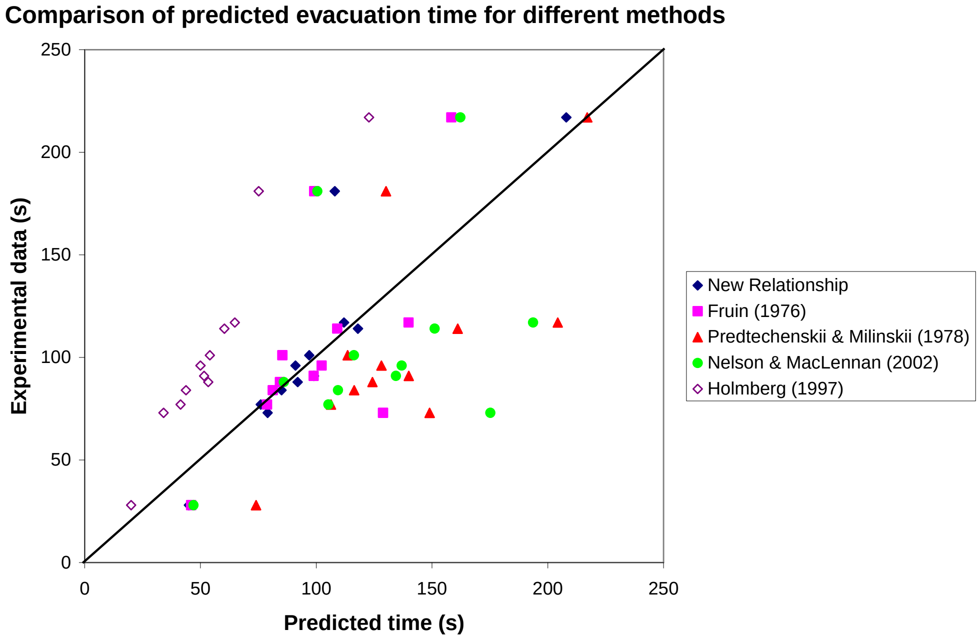


Figure 6.17: Comparison of predicted evacuation times for different relationships

Figure 6.17 shows the results from the calculation. Apparently, Holmberg's method gives a very short evacuation time in most of cases (Over 50% averaged error). Since the empirical equation is based on the experiments where people were asked to walk along a segment of passageway, the movement speed is expected to be faster than uncontrolled evacuation practice. Only one parameter, the width of congestion point, is required in the equation, which seems to be too simple to handle a case as complicated as a lecture theatre evacuation. It can be concluded that Holmberg's method is not appropriate to represent the crowd movement in lecture theatres.

Methods from Nelson & MacLennan and Predtechenslii & Milinskii, which are better developed from widely different experimental data, give similar predictions in most of cases but have a tendency to overestimate the evacuation time. Also, the average prediction error is more than 50% for both methods.

For Nelson & MacLennan, occupant density used in the calculation is the density of entire room. There is no specific approach to obtain the actual queuing density at a congestion point. This assumption might cause a lower estimation of flow rate, and accordingly a longer evacuation time. Alternatively, one trial is made using the maximum specific flow (1.3 persons/s/s), specified in the study, to calculate the evacuation time. A shorter result is obtained which is much lower than the actual experimental data. Besides, the “k” factor used in the calculation is for an aisle or doorway where people actually exit. Basically, this method is able to give a comparable prediction for lecture theatres. To pursue a more accurate calculation, more detailed information about movement at a doorway needs to be provided for consideration.

For the calculation of the method from Predtechenslii & Milinskii, a crucial unique parameter needs to specified, the density expressed as the ratio of the sum of horizontal projections of people to the floor area occupied by the flow. For this case, a value 0.125 m^2/m^2 is used for the calculation (Thompson and Marchant, 1995). It should be noted that this method gives a perfect prediction in the case of Weckman’s theatre (217s, the same as the experiment data). This method is more appropriate in a building where a large number of people are present.

The method from Fruin gives a reasonable prediction in most cases with an average error of 27.7%. This might be because the experiment setup with a similar walking environment in the lecture room was implemented.

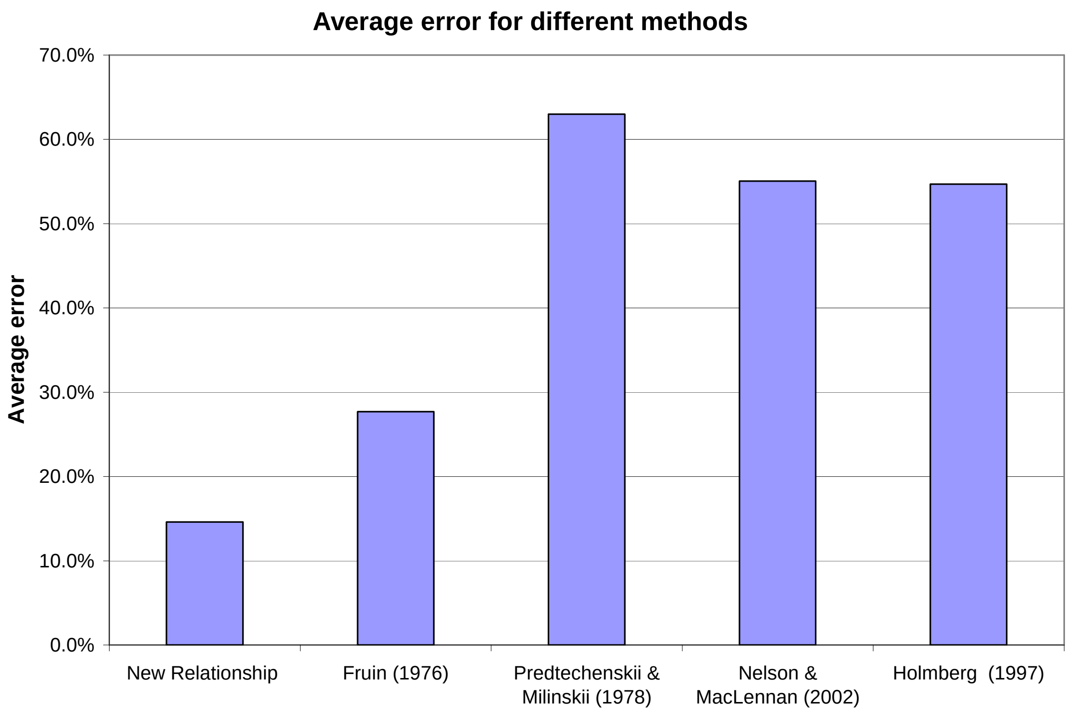


Figure 6.18: Average error for different methods

Based on the comparison with experimental data, it shows that the new method gives the best prediction of evacuation time, with averaged error of 14.6%. For its purpose of development, this method is most appropriate to estimate the evacuation time in the case of lecture theatre type rooms. Thus, incorporating this method into a computer model is worthwhile for fire safety design. However, this new relationship is only suitable for a range of occupant densities between 0.24 to 1.05 persons/m^2. Out of this range, more experimental verification needs to be achieved.

6.7 Limitation of the new method

As the new relationship is derived from one set of experiment data, the validation needs to be carried out in terms of the range of occupant density and various building geometries. In conclusion of the prediction from the previous analysis, limitation or restriction of the new method is made for proper usage.

In terms of occupant:

- ❖ The population of occupant should not include the disabled people or people with impaired mobility.
- ❖ The population should be mainly formed by young adults or students with light clothing.
- ❖ The occupant is expected to be familiar with evacuation procedures or be well directed during the evacuation.
- ❖ The acceptable occupant density for this method is suggested as a range of 0.24 ~ 1.05 persons/m^2, which is based on the used experimental data.

In terms of features of the lecture theatre:

- ❖ The size of the room is recommended to be over 100m^2.
- ❖ The floor is declining from back to front.

7 Modelling and Recommendation of EvacuatioNZ

In this chapter, the evacuation drills in eight lecture rooms (A1 to A3, C1 to C2, S2 and S4) are modelled using EvacuatioNZ to judge the suitability in predicting evacuation time of lecture theatres. Three experiment data sets extracted from other researches are also modelled for comparison purpose. In terms of the conditions in the lecture theatres, two scenarios are specified by varying the occupant density. The results from the modelling are compared with the experiment data and the prediction from the new method.

7.1 Scenario 1: Normal geometry

7.1.1 Input

In Scenario 1, all the lecture rooms are modelled with their original geometry. Every room is treated as a single node. Each exit is regarded as a safe node i.e. once people reach these nodes, the evacuation process is finished. For example:

```
<Node exists="Yes">
   <Name>Room_1</Name>
   <Ref>1</Ref>
   <Length>16</Length>
   <Width>20</Width>
</Node>
<Node exists="Yes">
   <Name>Exit_Main</Name>
   <Ref>2</Ref>
   <NodeType>Safe</NodeType>
</Node>
```

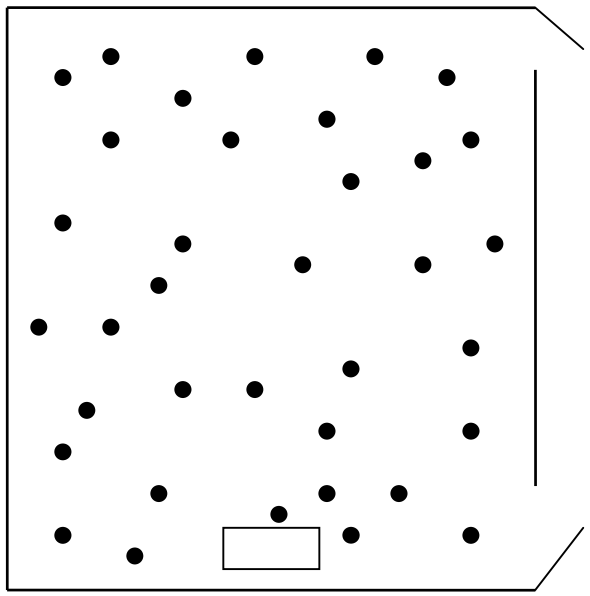


Figure 7.1: Sketch of room geometry and random start feature

Figure 7.1 is the sketch of room geometry. In order to simulate the uncertainty of start position, occupants are distributed randomly in the node by adding in an order, "`<RandomStartPosition>Yes</RandomStartPosition>` in SCENARIO file. This random start feature gives a range of evacuation times as people's start positions are different in every simulation making the model more realistic. (Teo, 2001) However, this feature is still not able to satisfy the realistic simulation of lecture theatres as the fixed seat rows restrict people's movement towards exits. This will be discussed in Scenario 2.

In terms of exit behaviour, there are eight options to simulate different situations. In order to simulate the exit choice in the experiment, preferred route (Preferred) and exit sign route (ExitSign) are selected for exits. For example:

```
<ExitBehaviour name="Default1">
   <ExitBehaviourType type="Preferred">
      <Probability>100</Probability>
   </ExitBehaviourType>
</ExitBehaviour>
 <ExitBehaviour name="Default2">
   <ExitBehaviourType type="ExitSign">
      <Probability>100</Probability>
   </ExitBehaviourType>
</ExitBehaviour>
```

The main entrance, typically located at the front, is designated as the preferred route because the students in the class are expected to be familiar with the building. On the other hand, alternative exit, typically located at the back, is designated by the exit sign route in order to distribute a portion of occupants to use the fire exit instead of the main entrance. For example:

```
 <Connection exists="Yes">
   <Name>Route_Main</Name>
   <NodeRef>1</NodeRef>
   <NodeRef>2</NodeRef>
   <Length>0</Length>
   <ConnectionType type="Door">
      <Width>1.65</Width>
   </ConnectionType>
    <ConnectionChoice type="Preferred"/>
</Connection>
<Connection exists="Yes">
   <Name>Route_Back</Name>
   <NodeRef>1</NodeRef>
   <NodeRef>3</NodeRef>
   <Length>0</Length>
   <ConnectionType type="Door">
      <Width>0.75</Width>
   </ConnectionType>
    <ConnectionChoice type="ExitSign"/>
 </Connection>
```

In POPULATE file, the population of each lecture room is divided into two portions. People who chose main entrances during the experiment are modelled to use preferred route while the rest of the people who chose alternative exits are modelled to use exit sign route. Nevertheless, when the model is applied to more than one exit behaviour, only half of the simulations give the desired outcome. In the other half of the simulations, there is only one exit used by the entire population due to the flaw in the model. (Ko, 2003)

In PERSON TYPE file, the potential maximum travel speed is specified as 1.2m/s (Buchanan, 2001). Due to poor information or description about the phase of pre-evacuation, the pre-movement time component is not added in. The final evacuation time is the sum of the result from modelling and the pre-movement time specified in the previous assumption. This makes the results more comparable with the prediction of the new method based on the same assumption.

Another important parameter in SIMULATION file is the local occupant density, which is the occupant density around a doorway where queuing takes place. This parameter is very similar to the "queuing density" in previous analysis. It has a maximum values of 3.5 ppl/m^2 suggested in the SFPE handbook (Nelson and Mowrer, 2002), which is reflects extreme circumstances unlikely in a typical fire evacuation. Thus, another lower value, 2.0 ppl/m^2, is suggested by Proulx (2002). This value is adopted in all cases. The equation to calculate flow rate is from Nelson & MacLennan's door flow correlation. The SIMULATION file is shown as below:

```
 <TimeMax>1200</TimeMax>
 <TimeStep>1</TimeStep>
 <MaxNodeDensity>2</MaxNodeDensity>
 <DoorFlow>Maclennan</DoorFlow>
<OccupantDensityModellocalOccupantDensity="2.0">mixed/
OccupantDensityModel>
  </EvacuatioNZ_Simulation>
```

The input file of all lecture rooms is attached in Appendix G.

7.1.2 Result

As the random start feature is turned on, the model is able to give a range of evacuation times as a distribution rather than a single value. There are a total of 100 simulations for each case. Because of the defect in the component of exit behaviour, only half of the results are presented for comparison. Based on these fifty simulations, the results can be approximately represented by normal distribution with a relatively low standard deviation. (See Appendix H)

Generally, without the effect of restriction from fixed seats, the model underestimates the evacuation time with shorter results in Scenario 1. As the reason mentioned before, due to the restriction of fixed seat rows, the realistic movement of occupant in lecture room can not be described properly by the setup of Scenario 1 in EvacuatioNZ. The predicted evacuation times in Figure 7.2 are the mean values of normal distribution for simulation results.

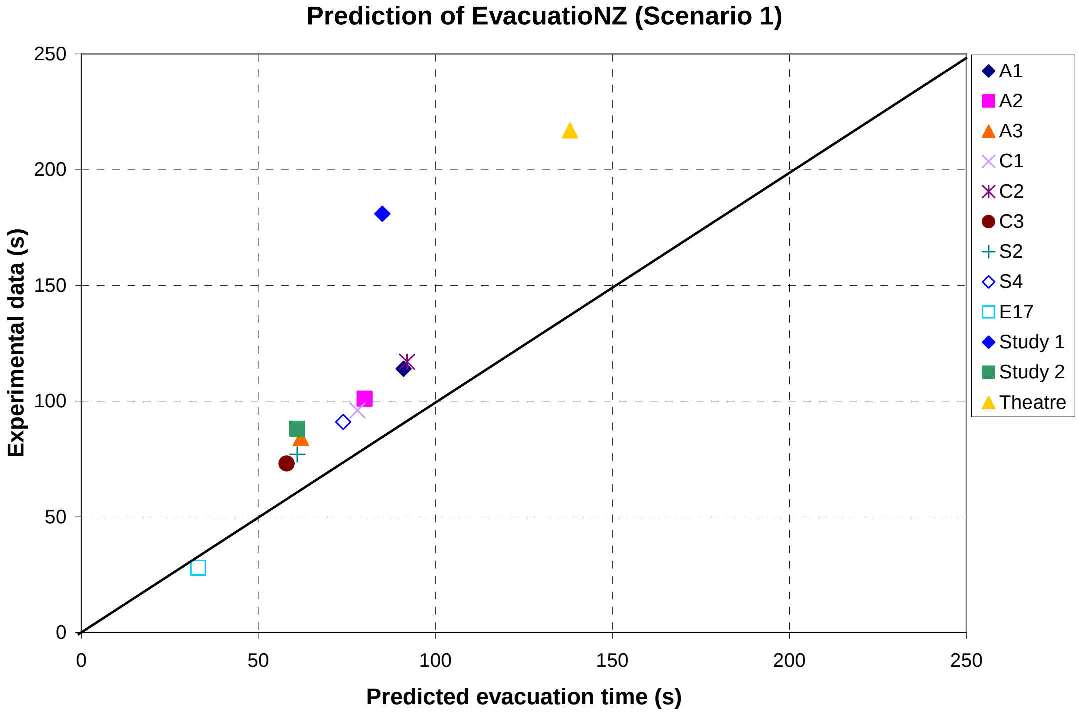


Figure 7.2: Prediction of EvacuatioNZ (Scenario 1)

In Figure 7.2, most prediction times are shorter than experimental data except for E17, which is a small-sized lecture room below 100m^2.On average, the model gives about 20% under predicted evacuation time, but in the case of Study 1, due to poor information specifying the pre-movement time, the error is above 50%.

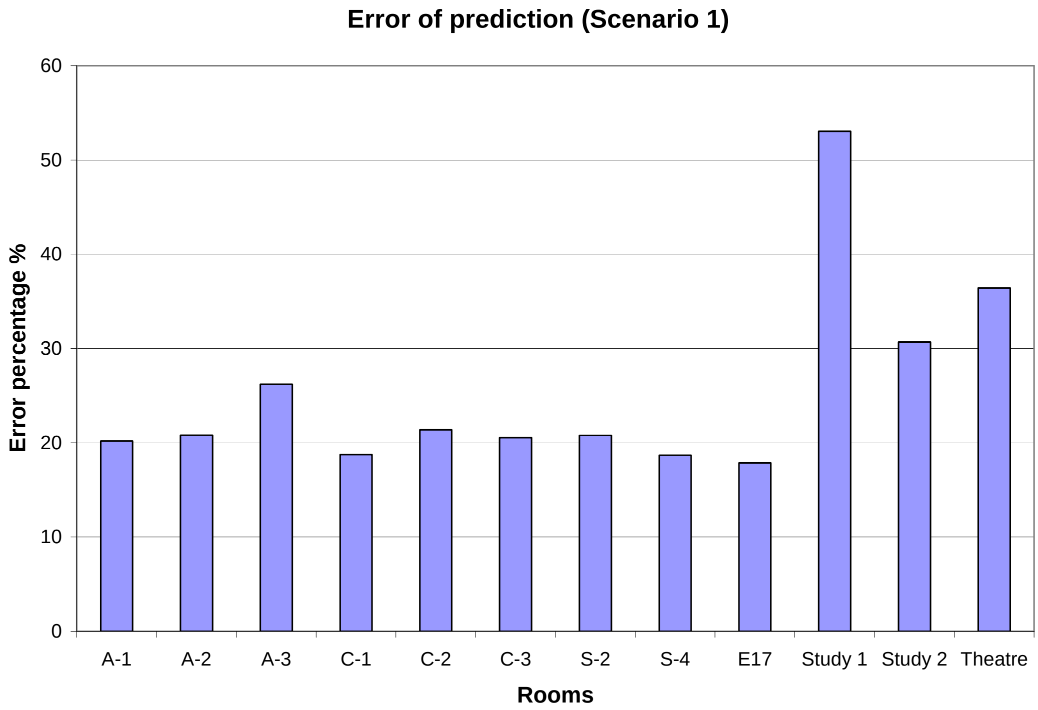


Figure 7.3: Error of the prediction for Scenario 1

7.2 Scenario 2: Alternative geometry

7.2.1 Input

In order to model the restriction of fixed seat rows, the geometry of the lecture rooms is modified in Scenario 2. Based on video observation, people filled up the aisle area at the very beginning stage after the pre-movement phase. As people left the aisle and approached the exits, others waiting between rows joined in the flow to occupy the spare space. Thus, it is reasonable to assume that the aisle area has a constant queuing density throughout the evacuation procedure. But this assumption is not appropriate if the room density is very low, which means that there are not enough occupants to replace the leaving people to make the aisle's density constant. To convert this assumption into the model, assume that all occupants are distributed in a designated area with the aisle width at initial stage. The density of this area is assumed to be the local density or the queuing density, which is 2.0 ppl/m^2 in the model. Dividing the population by the queuing density, the area is calculated and accordingly the length of this area can be calculated. When there are two aisles connected with the end of rows in the room, doubled aisle width is used for the designated area. Figure 7.4 gives a demonstration of the geometry setup. This process is similar as the analysis in Section 6.4.2.

In Scenario 2, except for MAP file, other setups are exactly same as Scenario 1. (See Appendix G)

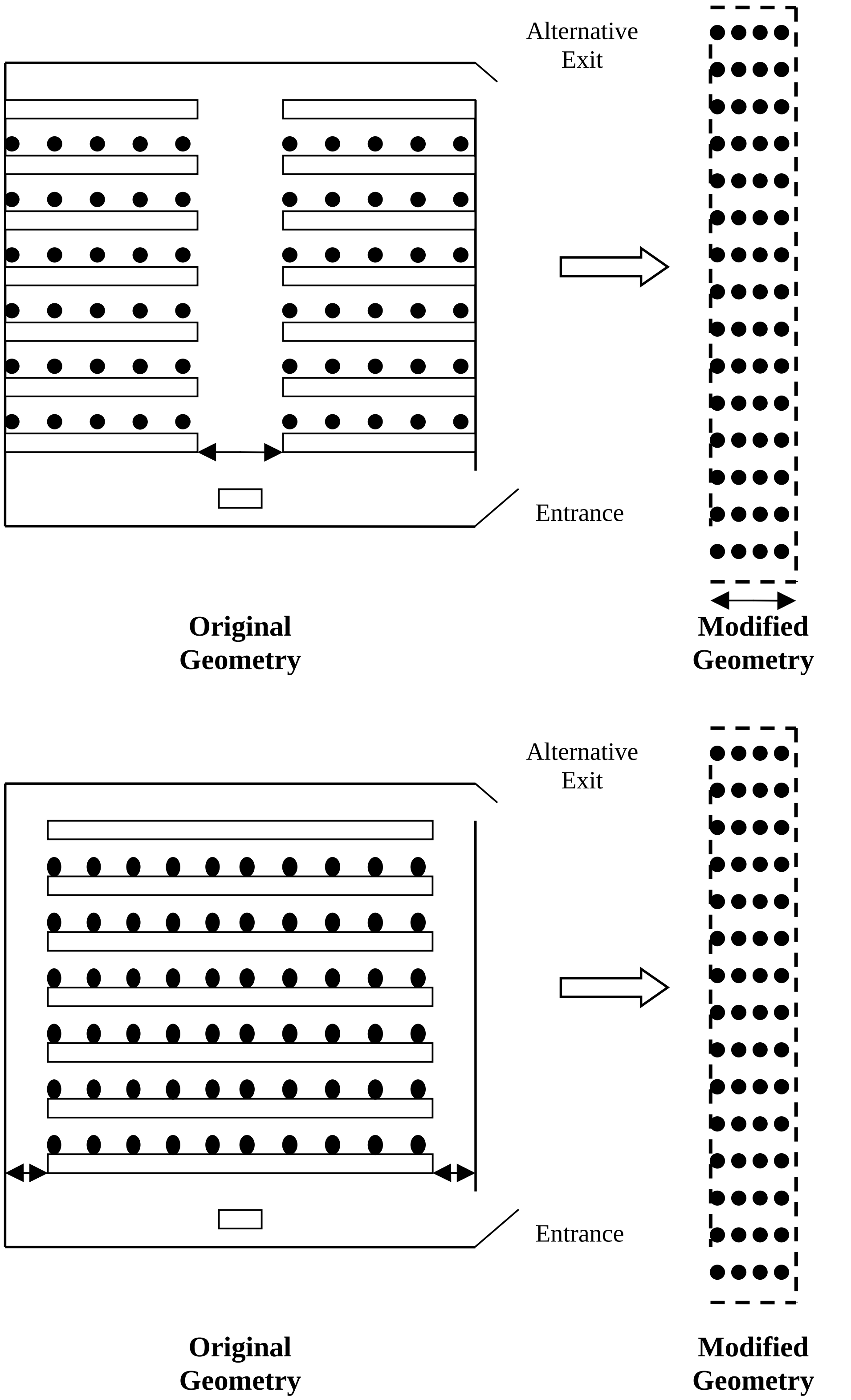


Figure 7.4: Sketch of modified geometry

7.2.2 Result

By using the modified geometry to take the effect of fixed seats into account, the model gives more accurate results for most cases. (See Appendix H) Figure 7.5 shows that the model with modified geometry input can not give an accurate result in the case of E17 and Study 1. In case E17, the predicted time is 55s with 96% overestimation. Hence, this alternative approach is not appropriate for small-sized lecture room. For case Study 1, although the error of prediction is reduced from 53% to 44% in Scenario 2, it is not accurate enough for modelling. This proves that the pre-movement time for Study 2 should not be treated as a single value. If two evacuation trials are under the same conditions, as for the case with a very long evacuation time like Study 2, usually pre-movement plays a more important role than queuing density as the duration of decision making might vary significantly for different individuals. Therefore, it is more realistic to introduce a distribution to represent the pre-movement time giving a wide range of evacuation time in this case.

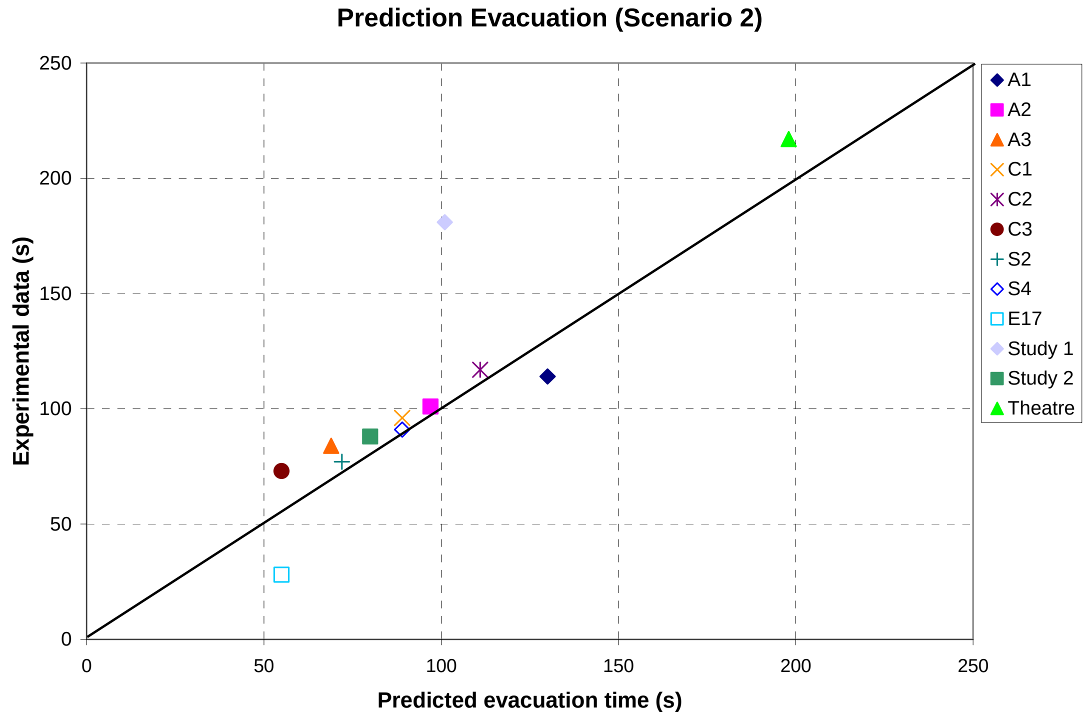


Figure 7.5: Prediction of EvacuatioNZ for Scenario 2

Except for case E17 and Study 2, Scenario 2 gives a more accurate prediction of evacuation time with averaged 9% error. Generally, it still underestimates the evacuation time in most cases.

Based on the modelling, a trend can be found that the higher the occupant density of the room, the more accurate the prediction. (See Figure 7.6) This relation is associated with the assumption made at the beginning in Scenario 2. If the initial room density is high, as a result of relatively high occupant load, there will be sufficient people provided to fill up the modified area. Accordingly, the occupant density within the designated area is more likely to be close to a consistent value defined as the local density in the model. Thus, the assumption is closer to the real situation. This trend is not very obvious due to the inadequate number of data presented.

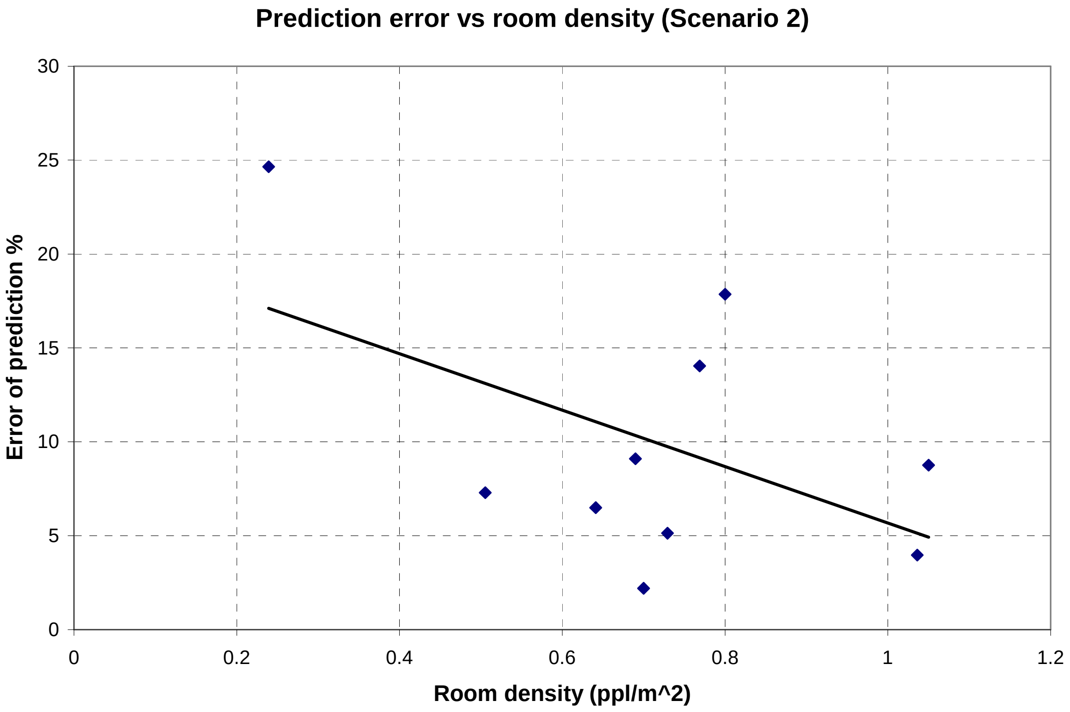
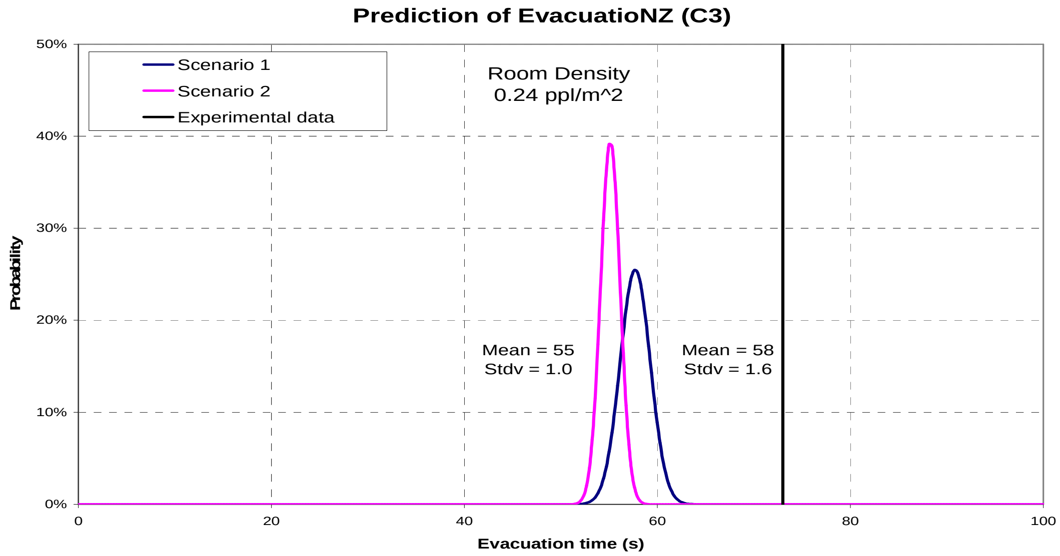


Figure 7.6: Relation between prediction error and room density in Scenario 2

On the contrary, if the occupant density is very low, Scenario 2 is more likely to give a similar prediction as Scenario 1 as the effect of queuing is reduced because of the low occupant density and most people will travel at their own speed, 1.2m/s in the model. Figure 7.7 gives a comparison between the predictions with room density of 0.24ppl/m^2 in C3 and 1.05ppl/m^2 in Theatre.



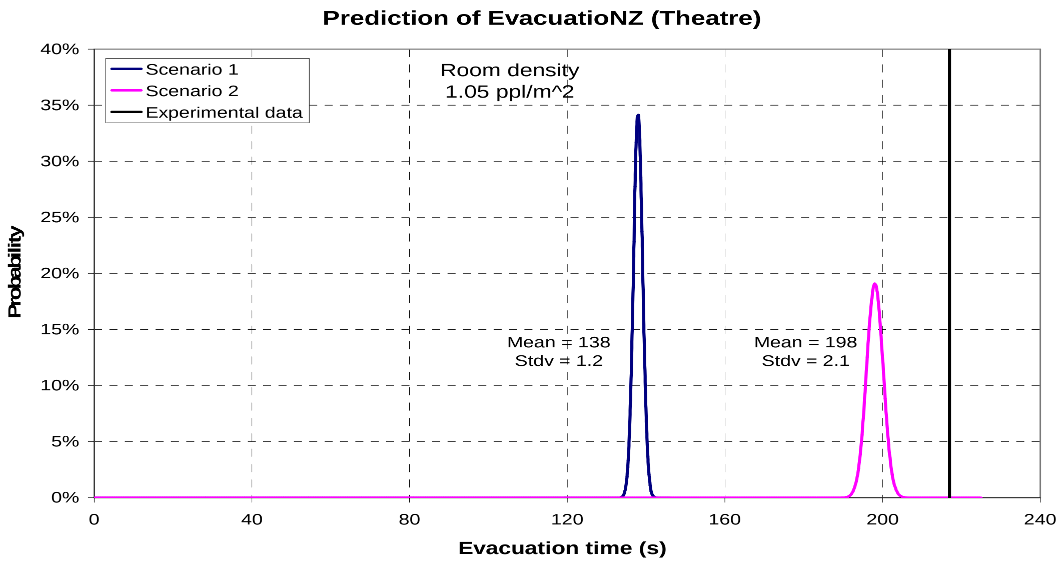


Figure 7.7: Prediction of EvacuatioNZ in case C3 and Theatre

Comparing the results from both scenarios (See Figure 7.8), it can be concluded that for most of cases, Scenario 2 gives a better prediction of the evacuation time. E17 is a special case in which very little impact on movement behaviour comes from seat restriction. Thus, Scenario 2 is not a appropriately physical model for E17. In general, the application of the alternative approach is recommended when dealing with the modelling regarding lecture theatres.

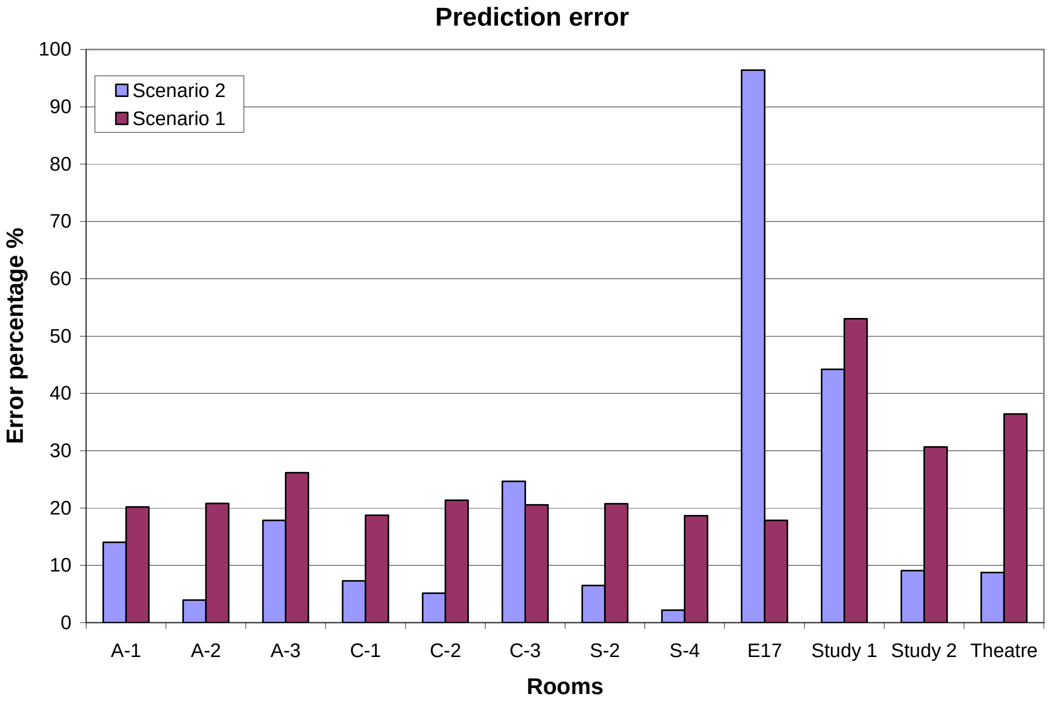


Figure 7.8: Prediction error of Scenario 1 & 2

7.3 Comparison with prediction of the new method

From previous discussion, Scenario 2 has a better performance of prediction. Thus, using the results from Scenario 2 to compare with the results from the new method, it can be seen that the predictions from two approaches are similar with difference of about 10% in average. In general, the new method gives a slightly more accurate prediction than Scenario 2. (See Figure 7.9) Although the new method needs to be verified in a wide range of occupant density, it is valuable to apply this new method to EvacuatioNZ for modelling of lecture theatre type of room.

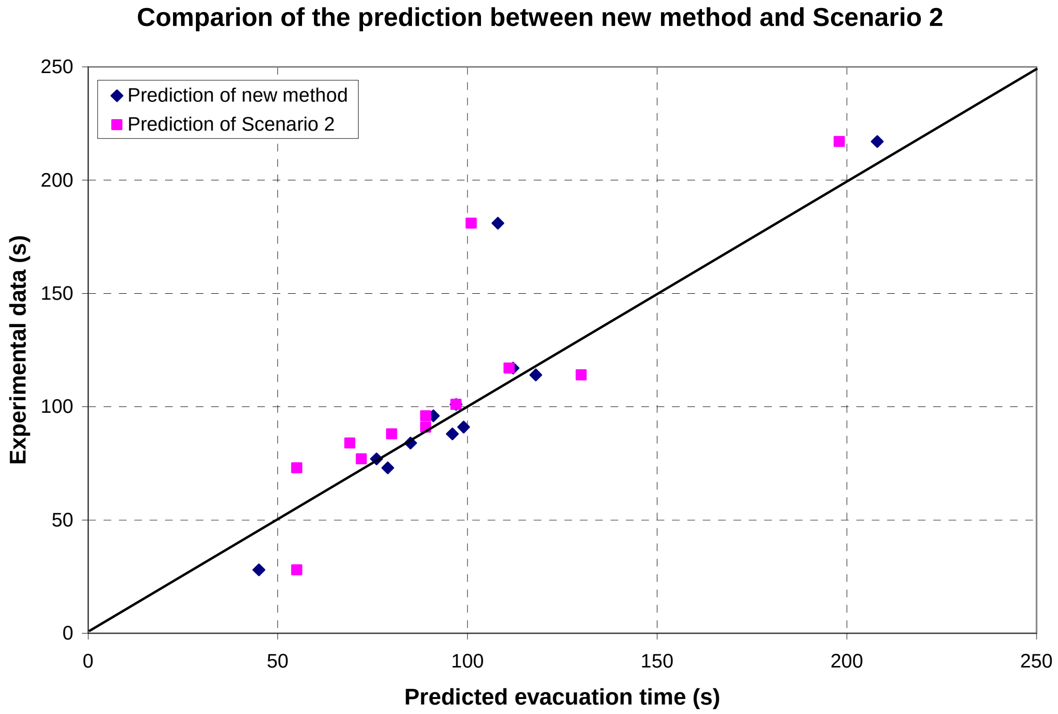


Figure 7.9: Comparison of the prediction between the new method and Scenario2

7.4 Recommendation of EvacuatioNZ

According to previous comparison with the method from MacLennan and Nelson, the new method gives a more accurate prediction of evacuation time in a certain range of room density, particularly for lecture theatre type of room. More works needs to be done to verify and improve this new relationship. In order to model such a room with complicated obstacle restriction like theatres in EvacuatioNZ, it is worthwhile to incorporate this new relationship into the model to assess its availability. To achieve the modification, the following approach is recommended.

1) Create a new node type named" Lecture", which is required to specify the aisle width in MAP file.

```
<Node exists="Yes">
   <Name>Lecture1</Name>
   <Ref>1</Ref>
   <Length>16</Length>
   <Width>20</Width>
   <AisleWidth>1.8</AisleWidth>
   <NodeType>Lecture</NodeType>
</Node>
```

2) The comparison between door width and aisle width should be presented to determine the effective width for each egress route.

3) Add the new relationship into the model so that the user can choose from SCENARIO file. The maximum node density and local occupant density is not effective on the "Lecture" type node as all these parameters are calculated from the room density in the new relationship.

```
<EvacuatioNZ_Simulation version="1.01">
     <TimeMax>1200</TimeMax>
     <TimeStep>1</TimeStep>
    <DoorFlow>NewRelashionship</DoorFlow>
</EvacuatioNZ_Simulation>
```

The modification work needs to be carried out further. Once the new relationship is added in, the modified model should be verified by simulating more actual evacuation trials. The confidence of the application will be judged from the comparison between simulation results and experimental data.

8 Conclusion and Recommendation

8.1 Conclusion

According to the observation of the experiment conducted in this research, three points need to be addressed in terms of exit choice behaviour, particularly in lecture theatres:

- The location of exits will strongly affect occupant's decision of egress route. More people tend to use the fire exit if it is installed closer to the main entrance (e.g. mid-way of side wall)

- Gradient surface of floor will also influence people's movement behaviour. Most occupants tend to go downwards to use the main entrance rather than go upward to use a fire exit.

- Occupant distribution in the auditorium area is another crucial factor determining the exit choice behaviour, particularly in the case where the occupancy in the lecture is relatively low.

Based on the numerical analysis from obtained data, an empirical equation to calculate specific flow for lecture theatre rooms is developed as follows:

$$Specific \quad flow = 0.92 \times D_{room}^{0.34}$$

Effective width used for each egress route will be the narrower width of door and aisle. Some limitations on this equation are presented as:

- The population of occupants should not include disabled people or people with impaired mobility.

- The population should be mainly formed by young adults or students with light clothing.

- The occupant is expected to be familiar with evacuation procedures or be well directed during the evacuation.

- The acceptable occupant density for this method is suggested as a range of 0.24 ~ 1.05 persons/m^2, which is based on the experiment data used for derivation.

- The size of the lecture room is recommended to be over 100m^2 large.

- The floor is declining from back to front.

According to the comparison with other empirical relationships between movement speed and flow rate, the developed equation gives better prediction in most cases of lecture theatres.

Generally, the current version of EvacuatioNZ is not able to give a relatively accurate prediction of evacuation time for lecture theatre rooms. With the alternative solution (Scenario 2 in Chapter 7), the model's performance can be improve with limited degree.

8.2 Recommendation

As the developed equation is only based on one series of experiment data obtained by the author, verification is essential and necessary to have confidence in its predictions. More experiments should be conducted in various sizes of lecture rooms.

To improve the EvacuatioNZ in advance, the new version with added empirical equation should be tested and compared with real life situation for accuracy. For design purpose, a safety factor is recommended to be added to give a conservative evacuation time.

In terms of the human behaviour aspect, particularly for lecture theatre rooms, impact from the location of fire exit, gradient floor, and the distribution of the occupants, shall be described in a quantitative way. This requires a great deal of further work and experimentation.

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APPENDIX A Experimental data

	A1					
	Main Entrance		Left side exit		Right side exit	
Time (s)	**Recorded no. of ppl**	**Cumulative no. of ppl**	**Recorded no. of ppl**	**Cumulative no. of ppl**	**Recorded no. of ppl**	**Cumulative no. of ppl**
		105		**78**		**63**
13	3	3	0	0	0	0
14	0	3	0	0	0	0
15	0	3	0	0	0	0
16	2	5	1	1	0	0
17	0	5	0	1	0	0
18	3	8	1	2	1	1
19	2	10	0	2	0	1
20	0	10	2	4	0	1
21	2	12	0	4	1	2
22	0	12	0	4	0	2
23	3	15	2	6	0	2
24	0	15	0	6	0	2
25	0	15	0	6	0	2
26	1	16	2	8	0	2
27	2	18	0	8	0	2
28	0	18	1	9	1	3
29	3	21	0	9	1	4
30	0	21	2	11	1	5
31	2	23	0	11	1	6
32	0	23	1	12	1	7
33	2	25	0	12	1	8
34	2	27	1	13	1	9
35	0	27	0	13	1	10
36	2	29	0	13	1	11
37	0	29	2	15	1	12
38	0	29	0	15	1	13
39	4	33	2	17	2	15
40	0	33	0	17	0	15
41	2	35	0	17	1	16
42	0	35	1	18	1	17
43	3	38	0	18	1	18
44	0	38	2	20	2	20
45	0	38	0	20	0	20
46	0	38	2	22	1	21
47	3	41	0	22	1	22
48	2	43	2	24	1	23
49	1	44	0	24	0	23
50	0	44	2	26	2	25
51	0	44	0	26	1	26
52	0	44	0	26	2	28
53	3	47	2	28	0	28
54	2	49	0	28	1	29
55	0	49	1	29	1	30

56	0	49	2	31	1	31
57	3	52	0	31	1	32
58	0	52	1	32	0	32
59	0	52	1	33	1	33
60	0	52	0	33	1	34
61	0	52	0	33	1	35
62	4	56	2	35	0	35
63	0	56	2	37	1	36
64	0	56	0	37	0	36
65	2	58	0	37	1	37
66	0	58	1	38	1	38
67	3	61	1	39	1	39
68	0	61	1	40	0	39
69	2	63	2	42	1	40
70	0	63	0	42	1	41
71	0	63	1	43	1	42
72	0	63	2	45	1	43
73	0	63	0	45	1	44
74	3	66	1	46	1	45
75	0	66	0	46	0	45
76	3	69	2	48	2	47
77	2	71	0	48	1	48
78	3	74	0	48	1	49
79	0	74	1	49	1	50
80	2	76	0	49	0	50
81	0	76	2	51	1	51
82	3	79	0	51	1	52
83	0	79	2	53	0	52
84	0	79	0	53	1	53
85	2	81	2	55	2	55
86	2	83	0	55	1	56
87	0	83	2	57	0	56
88	2	85	0	57	1	57
89	2	87	2	59	0	57
90	1	88	0	59	1	58
91	1	89	0	59	1	59
92	0	89	1	60	1	60
93	1	90	0	60	1	61
94	0	90	2	62	0	61
95	2	92	2	64	1	62
96	1	93	0	64	1	63
97	1	94	2	66		
98	1	95	0	66		
99	0	95	0	66		
100	1	96	0	66		
101	0	96	0	66		
102	1	97	2	68		
103	1	98	2	70		
104	0	98	0	70		
105	0	98	0	70		
106	1	99	2	72		
107	2	101	0	72		

108	2	103	1	73		
109	0	103	2	75		
110	0	103	0	75		
111	2	105	2	77		
112			0	77		
113			0	77		
114			1	78		

	A2				A3			
	Front Entrance		Back Exit		Front Entrance		Back Exit	
Time (s)	**Recorded no. of ppl**	**Cumulative no. of ppl**	**Recorded no. of ppl**	**Cumulative no. of ppl**	**Recorded no. of ppl**	**Cumulative no. of ppl**	**Recorded no. of ppl**	**Cumulative no. of ppl**
		122		**49**		**95**		**1**
13	2	2	0	0	0	0	0	0
14	0	2	0	0	0	0	0	0
15	2	4	0	0	0	0	0	0
16	2	6	0	0	0	0	0	0
17	0	6	0	0	0	0	0	0
18	2	8	1	1	2	2	0	0
19	0	8	0	1	0	2	0	0
20	2	10	0	1	0	2	0	0
21	2	12	0	1	0	2	0	0
22	2	14	1	2	0	2	0	0
23	2	16	1	3	5	7	0	0
24	0	16	0	3	0	7	0	0
25	2	18	0	3	0	7	0	0
26	0	18	1	4	6	13	0	0
27	2	20	1	5	0	13	0	0
28	0	20	1	6	0	13	0	0
29	2	22	0	6	6	19	0	0
30	2	24	1	7	0	19	0	0
31	2	26	0	7	0	19	0	0
32	2	28	1	8	0	19	0	0
33	2	30	0	8	0	19	0	0
34	0	30	1	9	6	25	0	0
35	2	32	0	9	0	25	0	0
36	0	32	1	10	0	25	1	1
37	5	37	0	10	6	31		
38	0	37	1	11	0	31		
39	0	37	0	11	5	36		
40	5	42	1	12	0	36		
41	0	42	1	13	0	36		
42	0	42	1	14	5	41		
43	0	42	1	15	0	41		
44	5	47	0	15	5	46		
45	0	47	1	16	0	46		
46	0	47	1	17	0	46		
47	5	52	0	17	5	51		
48	0	52	0	17	0	51		
49	2	54	1	18	0	51		
50	0	54	0	18	5	56		

51	5	59	1	19	0	56		
52	0	59	1	20	5	61		
53	5	64	0	20	0	61		
54	0	64	1	21	5	66		
55	0	64	1	22	0	66		
56	5	69	0	22	0	66		
57	0	69	1	23	5	71		
58	0	69	0	23	5	76		
59	0	69	0	23	0	76		
60	0	69	1	24	5	81		
61	5	74	0	24	0	81		
62	0	74	1	25	5	86		
63	0	74	0	25	0	86		
64	5	79	0	25	5	91		
65	0	79	0	25	0	91		
66	0	79	1	26	0	91		
67	0	79	0	26	0	91		
68	5	84	1	27	0	91		
69	0	84	1	28	0	91		
70	0	84	1	29	0	91		
71	0	84	0	29	0	91		
72	5	89	1	30	2	93		
73	0	89	1	31	0	93		
74	0	89	0	31	0	93		
75	0	89	2	33	0	93		
76	5	94	0	33	0	93		
77	0	94	0	33	0	93		
78	0	94	2	35	0	93		
79	0	94	0	35	0	93		
80	5	99	1	36	0	93		
81	0	99	1	37	0	93		
82	0	99	1	38	0	93		
83	0	99	0	38	0	93		
84	0	99	1	39	2	95		
85	5	104	0	39				
86	0	104	2	41				
87	5	109	0	41				
88	0	109	0	41				
89	0	109	2	43				
90	2	111	1	44				
91	0	111	0	44				
92	0	111	1	45				
93	0	111	1	46				
94	0	111	1	47				
95	0	111	0	47				
96	5	116	1	48				
97	0	116	1	49				
98	0	116						
99	5	121						
100	0	121						
101	1	122						

	C1							
	Front Right Entrance		Front Left Entrance		Back Right Eixt		Back Left Exit	
Time (s)	**Recorded no. of ppl**	**Cumulative no. of ppl**	**Recorded no. of ppl**	**Cumulative no. of ppl**	**Recorded no. of ppl**	**Cumulative no. of ppl**	**Recorded no. of ppl**	**Cumulative no. of ppl**
		66		**54**		**38**		**34**
22	2	2	0	0	0	0	0	0
23	0	2	0	0	0	0	0	0
24	0	2	0	0	0	0	0	0
25	0	2	0	0	0	0	0	0
26	0	2	1	1	0	0	0	0
27	0	2	0	1	0	0	2	2
28	0	2	0	1	1	1	0	2
29	0	2	1	2	0	1	0	2
30	1	3	1	3	1	2	0	2
31	0	3	0	3	0	2	1	3
32	2	5	1	4	1	3	1	4
33	0	5	1	5	0	3	0	4
34	2	7	1	6	0	3	1	5
35	1	8	0	6	0	3	0	5
36	0	8	1	7	1	4	0	5
37	2	10	0	7	0	4	1	6
38	0	10	1	8	0	4	0	6
39	0	10	1	9	1	5	1	7
40	3	13	0	9	1	6	2	9
41	0	13	0	9	1	7	0	9
42	2	15	1	10	0	7	1	10
43	0	15	2	12	1	8	0	10
44	0	15	1	13	1	9	1	11
45	2	17	0	13	0	9	2	13
46	2	19	2	15	1	10	0	13
47	0	19	1	16	1	11	0	13
48	2	21	1	17	1	12	2	15
49	0	21	1	18	1	13	0	15
50	2	23	2	20	1	14	2	17
51	0	23	0	20	0	14	0	17
52	2	25	1	21	2	16	0	17
53	2	27	1	22	1	17	2	19
54	2	29	1	23	1	18	0	19
55	2	31	2	25	1	19	0	19
56	2	33	0	25	0	19	3	22
57	2	35	2	27	1	20	0	22
58	0	35	2	29	0	20	0	22
59	5	40	2	31	1	21	0	22
60	0	40	0	31	1	22	1	23
61	5	45	2	33	1	23	1	24
62	0	45	4	37	1	24	0	24
63	0	45	1	38	1	25	1	25
64	0	45	2	40	0	25	1	26
65	0	45	2	42	1	26	1	27
66	0	45	2	44	1	27	0	27
67	5	50	0	44	1	28	1	28

68	0	50	2	46	1	29	0	28
69	0	50	0	46	1	30	0	28
70	0	50	4	50	0	30	0	28
71	5	55	0	50	2	32	0	28
72	0	55	2	52	0	32	0	28
73	0	55	2	54	1	33	0	28
74	0	55			1	34	0	28
75	5	60			1	35	0	28
76	0	60			0	35	0	28
77	0	60			0	35	0	28
78	0	60			0	35	0	28
79	0	60			0	35	0	28
80	0	60			0	35	1	29
81	0	60			0	35	0	29
82	3	63			0	35	2	31
83	0	63			0	35	0	31
84	0	63			0	35	1	32
85	0	63			0	35	0	32
86	0	63			0	35	0	32
87	0	63			1	36	1	33
88	0	63			1	37	1	34
89	0	63			1	38		
90	0	63						
91	0	63						
92	0	63						
93	0	63						
94	0	63						
95	0	63						
96	2	65						
97	0	65						
98	1	66						

	C2				C3			
	Front Entrance		Back Exit		Front Entrance		Back Exit	
Time (s)	Recorded no. of ppl	Cumulative no. of ppl	Recorded no. of ppl	Cumulative no. of ppl	Recorded no. of ppl	Cumulative no. of ppl	Recorded no. of ppl	Cumulative no. of ppl
		155		**31**		**53**		**8**
21	1	1	0	0	1	1	0	0
22	0	1	0	0	0	1	0	0
23	1	2	0	0	0	1	0	0
24	1	3	0	0	1	2	0	0
25	1	4	0	0	0	2	0	0
26	1	5	1	1	0	2	0	0
27	1	6	0	1	1	3	0	0
28	1	7	0	1	2	5	0	0
29	1	8	2	3	1	6	0	0
30	2	10	0	3	1	7	1	1
31	1	11	0	3	1	8	0	1
32	0	11	0	3	1	9	0	1
33	1	12	0	3	0	9	0	1
34	1	13	0	3	1	10	0	1
35	1	14	5	8	0	10	3	4
36	1	15	0	8	2	12	0	4
37	1	16	0	8	2	14	0	4
38	0	16	0	8	0	14	0	4
39	1	17	0	8	0	14	0	4
40	1	18	0	8	3	17	3	7
41	1	19	0	8	0	17	0	7
42	0	19	3	11	2	19	0	7
43	2	21	0	11	2	21	0	7
44	0	21	0	11	2	23	1	8
45	1	22	0	11	3	26		
46	1	23	1	12	0	26		
47	1	24	0	12	2	28		
48	2	26	0	12	2	30		
49	0	26	0	12	2	32		
50	3	29	0	12	0	32		
51	3	32	0	12	0	32		
52	3	35	0	12	2	34		
53	0	35	0	12	3	37		
54	3	38	0	12	3	40		
55	0	38	0	12	0	40		
56	3	41	0	12	2	42		
57	0	41	0	12	2	44		
58	3	44	0	12	0	44		
59	3	47	0	12	0	44		
60	0	47	0	12	2	46		
61	2	49	0	12	0	46		
62	2	51	0	12	2	48		
63	2	53	0	12	2	50		
64	0	53	0	12	0	50		
65	2	55	5	17	1	51		
66	2	57	0	17	1	52		

67	2	59	0	17	0	52		
68	2	61	0	17	0	52		
69	3	64	0	17	0	52		
70	3	67	5	22	0	52		
71	0	67	0	22	0	52		
72	3	70	0	22	0	52		
73	3	73	1	23	1	53		
74	0	73	0	23				
75	3	76	0	23				
76	0	76	0	23				
77	3	79	0	23				
78	0	79	0	23				
79	3	82	0	23				
80	3	85	1	24				
81	3	88	0	24				
82	0	88	0	24				
83	3	91	0	24				
84	3	94	0	24				
85	0	94	5	29				
86	3	97	0	29				
87	3	100	0	29				
88	0	100	2	31				
89	3	103						
90	0	103						
91	3	106						
92	3	109						
93	0	109						
94	3	112						
95	3	115						
96	0	115						
97	3	118						
98	0	118						
99	3	121						
100	3	124						
101	0	124						
102	3	127						
103	0	127						
104	3	130						
105	0	130						
106	3	133						
107	0	133						
108	3	136						
109	3	139						
110	3	142						
111	2	144						
112	3	147						
113	3	150						
114	0	150						
115	2	152						
116	2	154						
117	1	155						

	S2				S4			
	Front Entrance		Back Exit		Front Entrance		Back Exit	
Time (s)	Recorded no. of ppl	Cumulative no. of ppl	Recorded no. of ppl	Cumulative no. of ppl	Recorded no. of ppl	Cumulative no. of ppl	Recorded no. of ppl	Cumulative no. of ppl
		56		44		63		63
15	0	0	1	1	0	0	0	0
16	0	0	0	1	0	0	0	0
17	0	0	0	1	0	0	2	2
18	0	0	1	2	0	0	0	2
19	0	0	0	2	0	0	0	2
20	0	0	0	2	0	0	0	2
21	1	1	0	2	0	0	0	2
22	1	2	1	3	0	0	0	2
23	1	3	0	3	1	1	2	4
24	1	4	1	4	1	2	0	4
25	0	4	0	4	1	3	2	6
26	1	5	1	5	1	4	0	6
27	1	6	0	5	1	5	2	8
28	0	6	0	5	0	5	0	8
29	1	7	0	5	1	6	0	8
30	0	7	1	6	0	6	2	10
31	1	8	0	6	3	9	0	10
32	1	9	1	7	0	9	0	10
33	0	9	0	7	2	11	2	12
34	1	10	1	8	0	11	0	12
35	1	11	0	8	1	12	2	14
36	1	12	1	9	2	14	2	16
37	2	14	1	10	1	15	0	16
38	0	14	1	11	0	15	2	18
39	2	16	1	12	2	17	0	18
40	2	18	2	14	1	18	2	20
41	0	18	1	15	0	18	2	22
42	2	20	0	15	2	20	0	22
43	0	20	1	16	0	20	2	24
44	0	20	1	17	3	23	0	24
45	2	22	1	18	0	23	2	26
46	2	24	0	18	2	25	0	26
47	2	26	2	20	0	25	2	28
48	2	28	0	20	3	28	0	28
49	0	28	1	21	2	30	2	30
50	2	30	1	22	2	32	2	32
51	2	32	1	23	0	32	0	32
52	0	32	1	24	2	34	0	32
53	3	35	0	24	0	34	0	32
54	3	38	1	25	0	34	2	34
55	0	38	1	26	3	37	0	34
56	3	41	0	26	0	37	0	34
57	3	44	1	27	2	39	2	36
58	0	44	0	27	0	39	0	36
59	0	44	2	29	0	39	2	38

60	3	47	0	29	3	42	0	38
61	0	47	1	30	2	44	2	40
62	0	47	1	31	0	44	0	40
63	0	47	1	32	2	46	0	40
64	3	50	1	33	2	48	2	42
65	0	50	2	35	0	48	2	44
66	2	52	0	35	2	50	0	44
67	0	52	2	37	3	53	0	44
68	2	54	0	37	0	53	2	46
69	0	54	2	39	2	55	0	46
70	1	55	0	39	0	55	2	48
71	0	55	0	39	2	57	2	50
72	0	55	2	41	0	57	0	50
73	0	55	0	41	1	58	0	50
74	0	55	0	41	2	60	2	52
75	0	55	2	43	0	60	0	52
76	0	55	1	44	1	61	0	52
77	1	56			2	63	2	54
78							0	54
79							0	54
80							2	56
81							0	56
82							0	56
83							0	56
84							2	58
85							2	60
86							0	60
87							0	60
88							2	62
89							0	62
90							0	62
91							1	63

APPENDIX B Occupant Density of Crowd Group

Figure B.1: Occupant density (A1 right aisle at 10s)

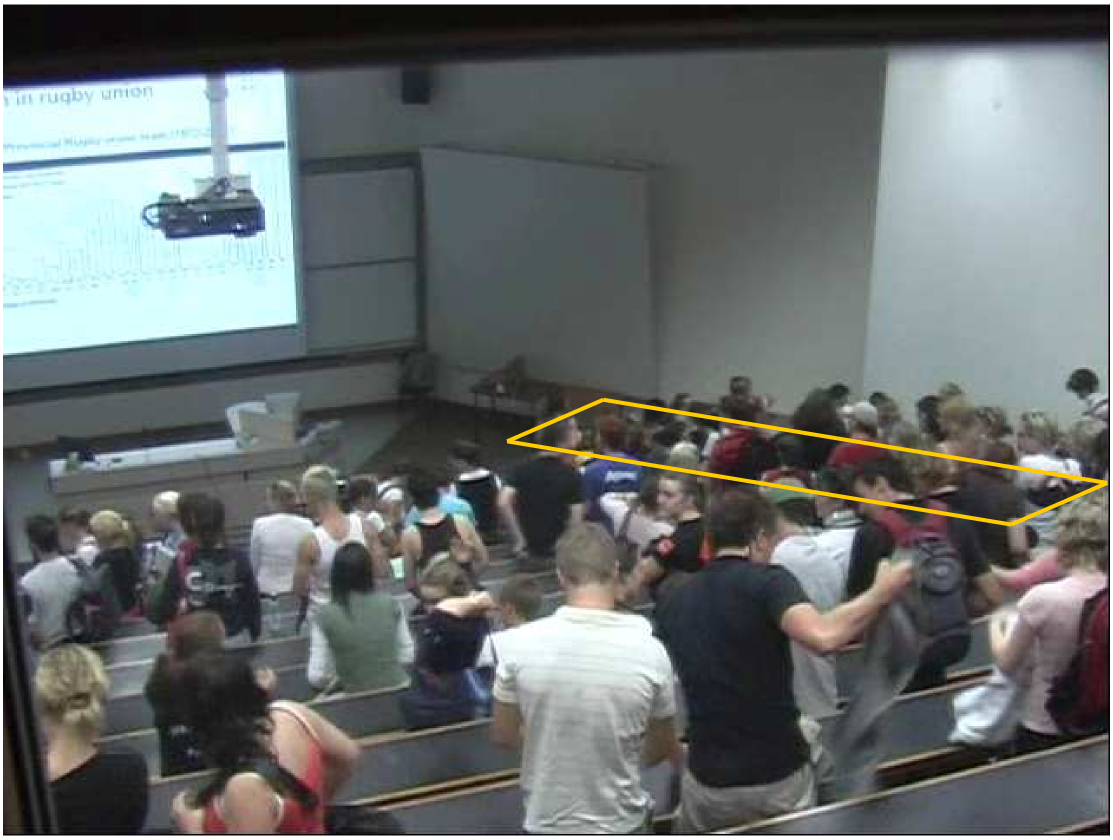

Figure B.2: Occupant density (A1 right aisle at 20s)

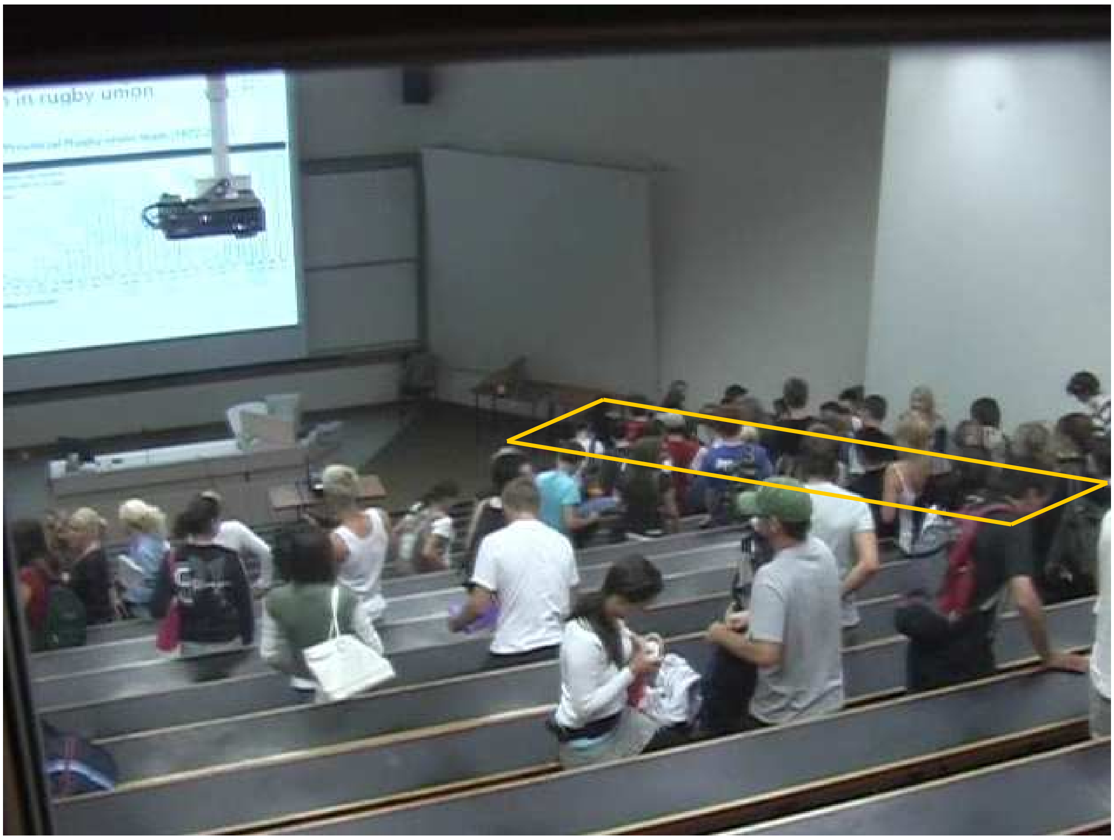

Figure B.3: Occupant density (A1 right aisle at 30s)

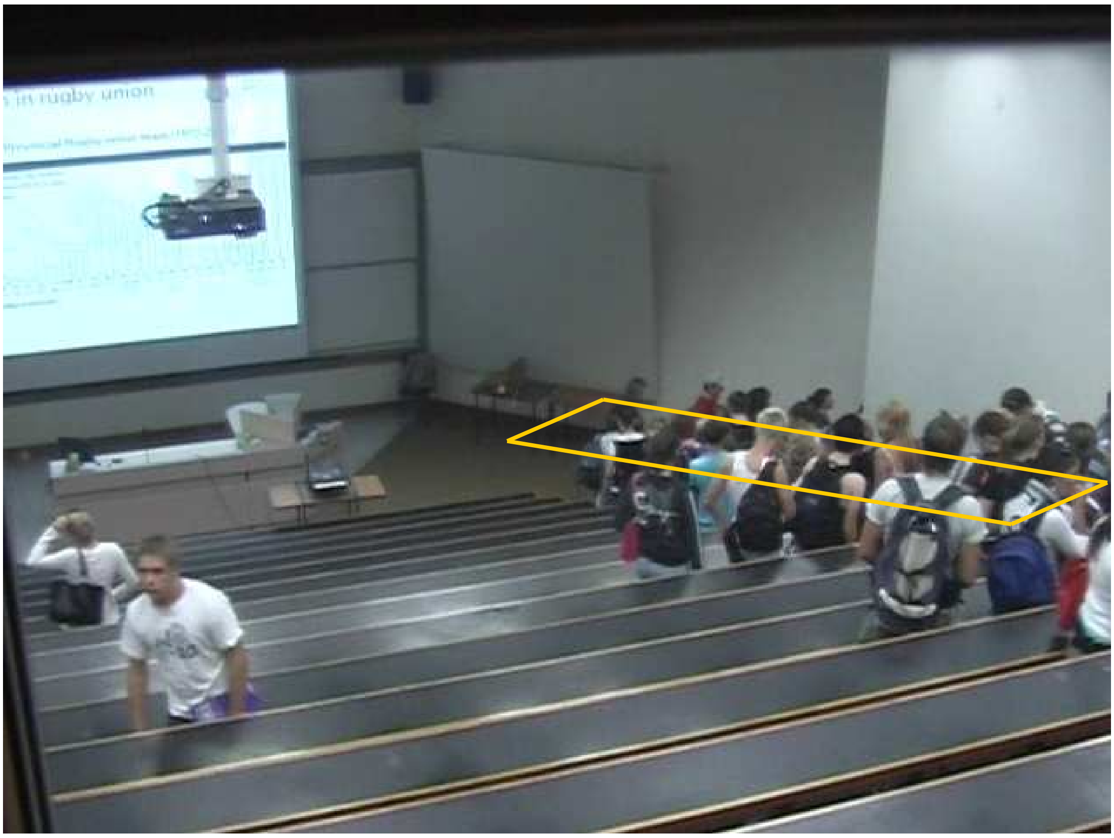

Figure B.4: Occupant density (A1 right aisle at 40s)

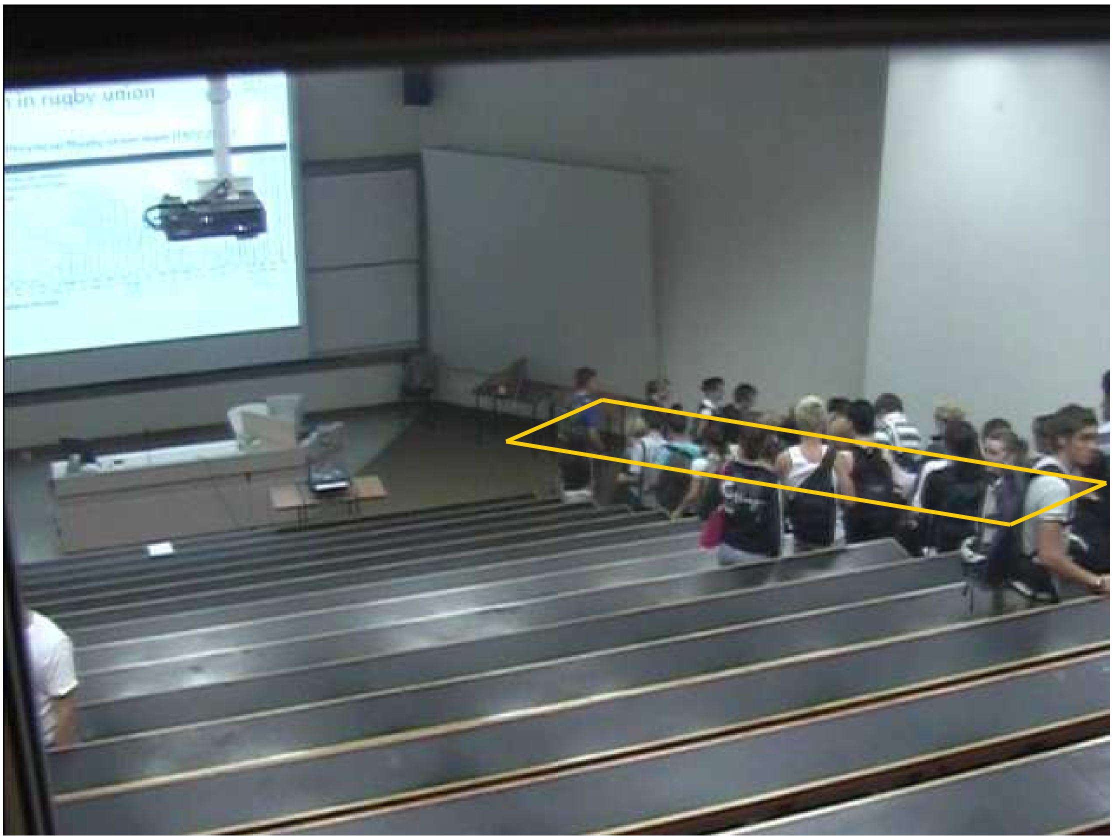

Figure B.5 : Occupant density (A1 right aisle at 50s)

Figure B.6: Occupant density (A1 left aisle at 10s)

Figure B.7: Occupant density (A1 left aisle at 20s)

Figure B.8: Occupant density (A1 left aisle at 30s)

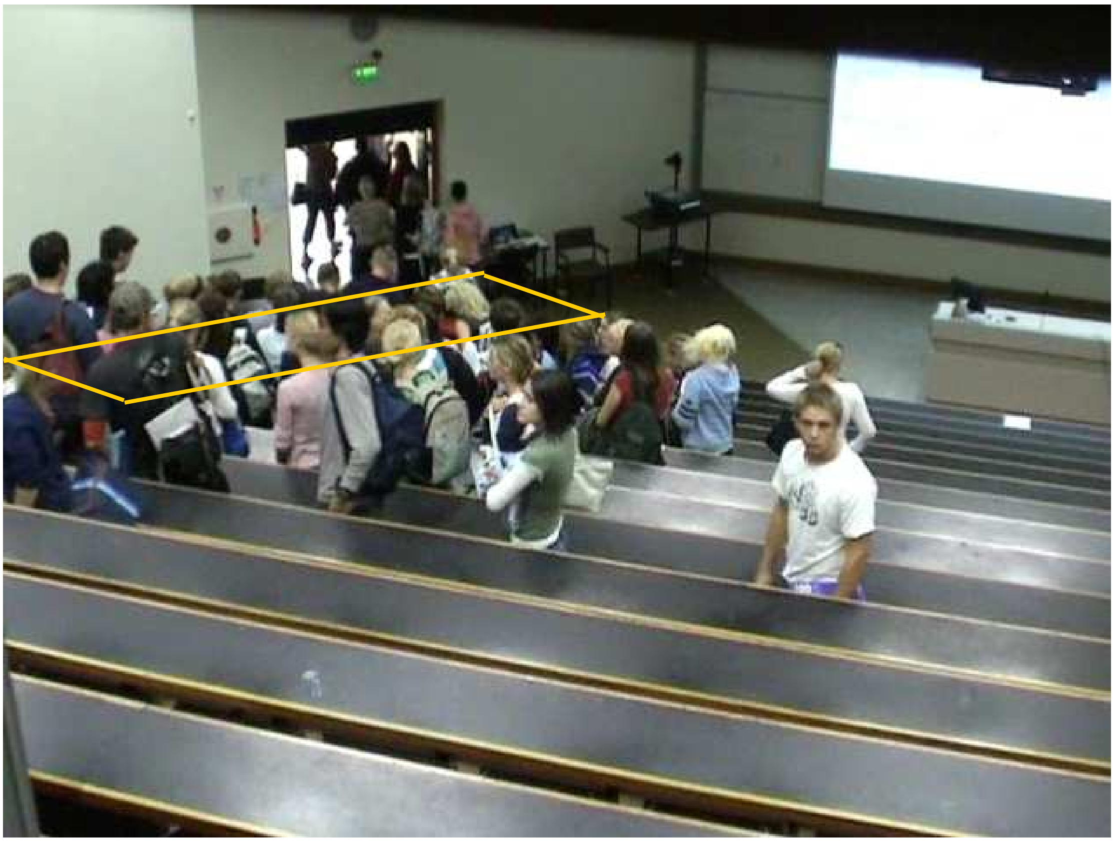

Figure B.9: Occupant density (A1 left aisle at 40s)

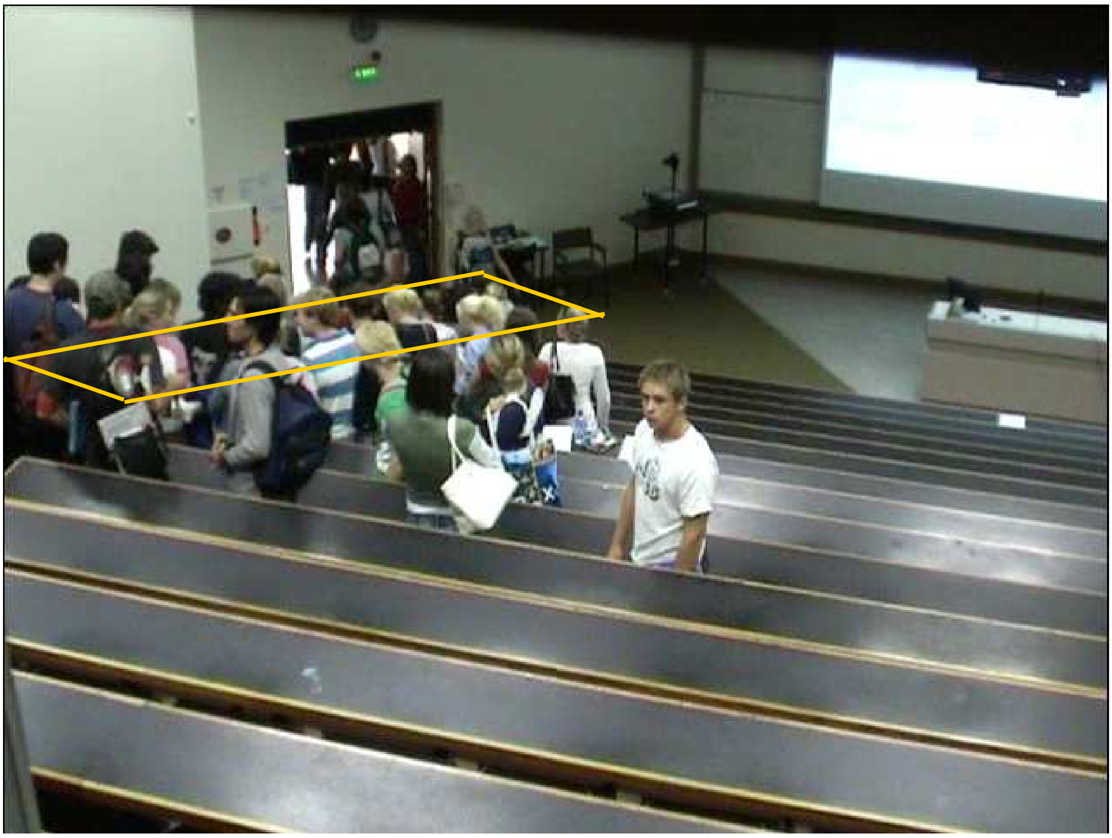

Figure B.10: Occupant density (A1 left aisle at 50s)

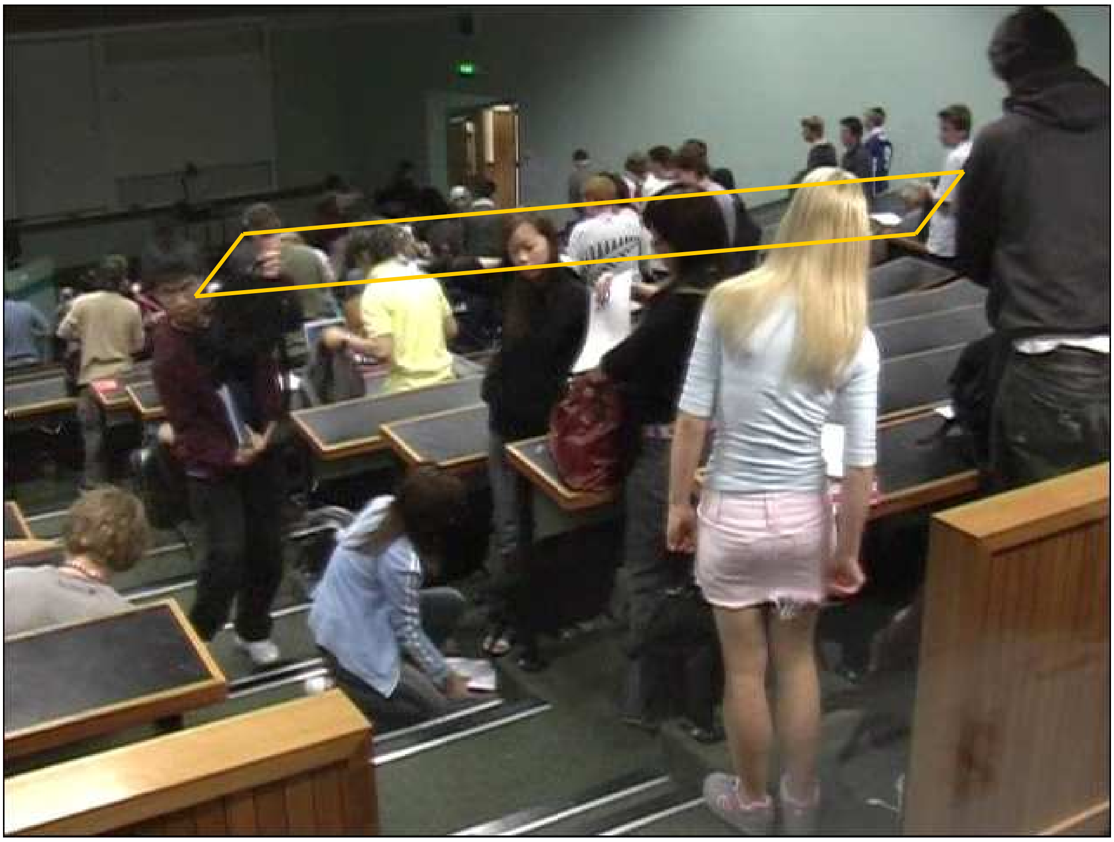

Figure B.11: Occupant density (C1 right aisle at 10s)

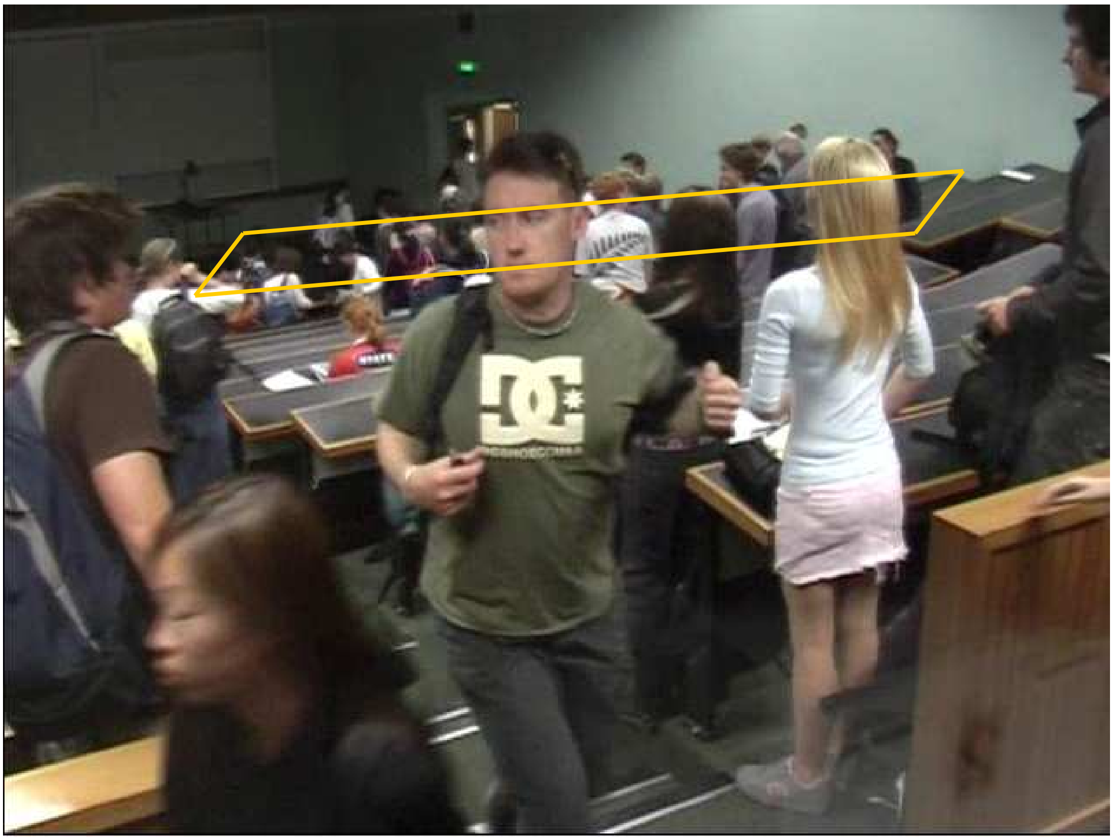

Figure B.12: Occupant density (C1 right aisle at 20s)

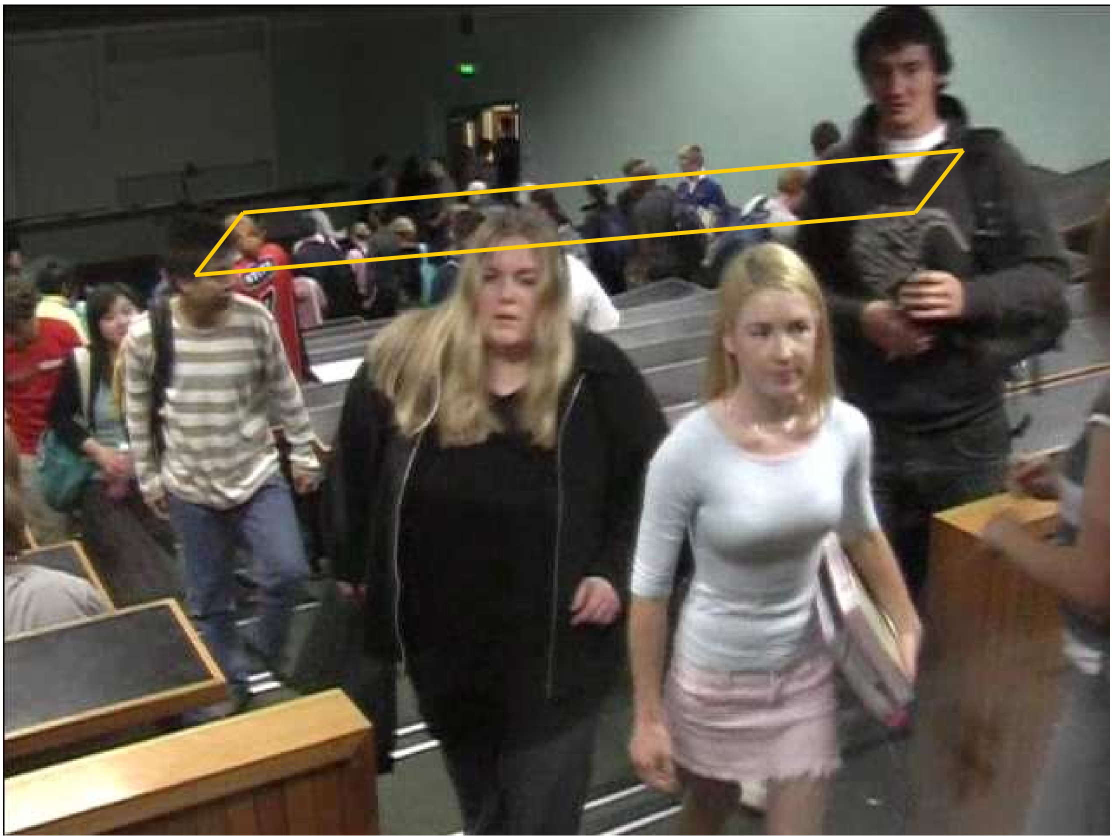

Figure B.13: Occupant density (C1 right aisle at 30s)

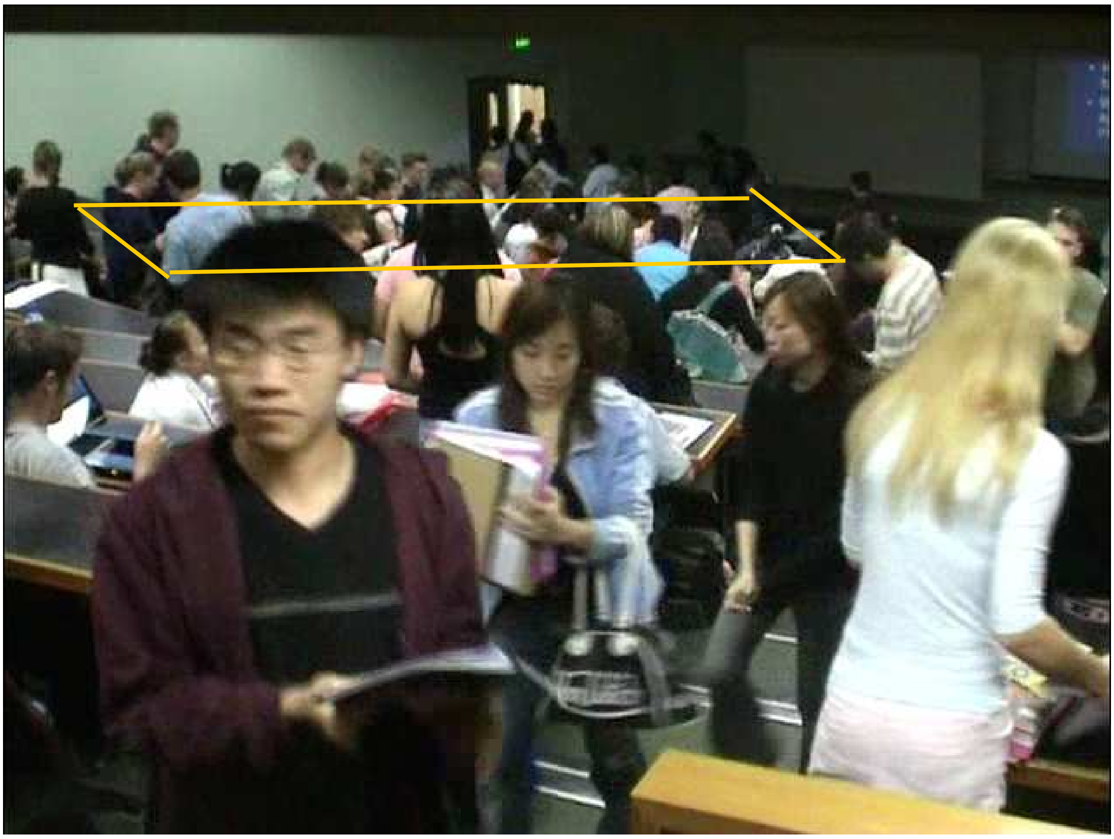

Figure B.14: Occupant density (C1 left aisle at 10s)

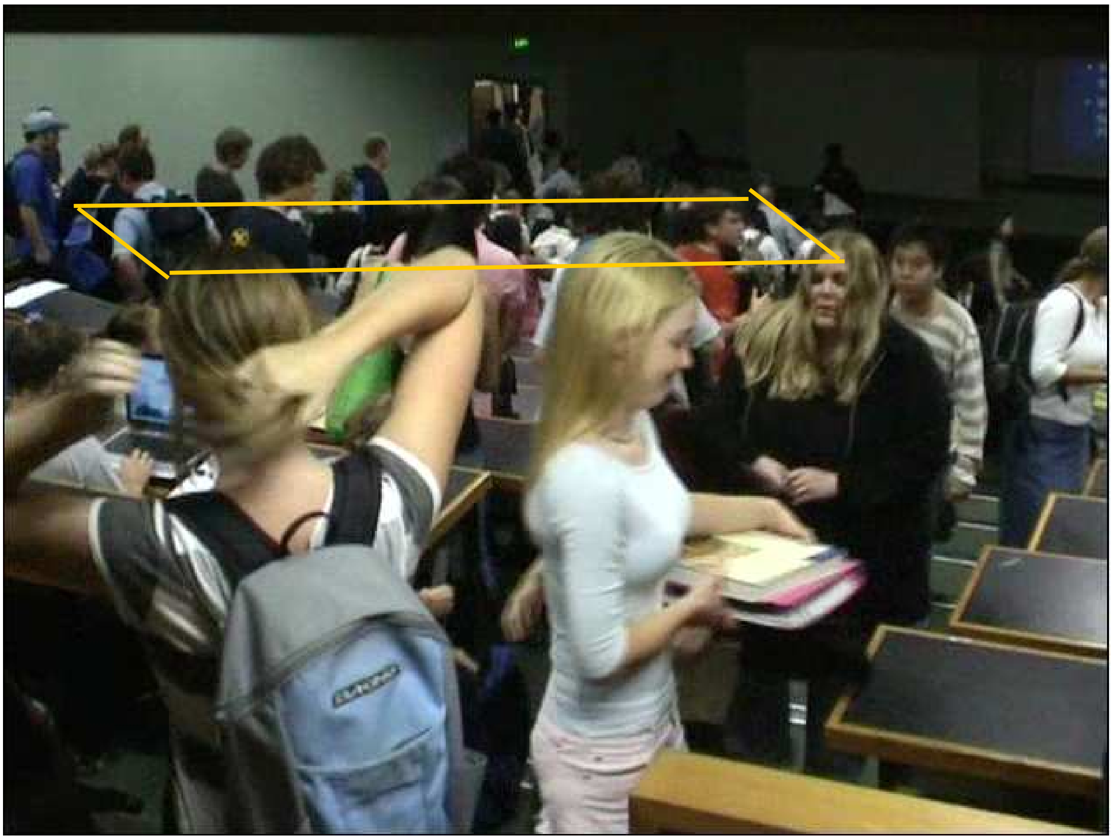

Figure B.15: Occupant density (C1 left aisle at 20s)

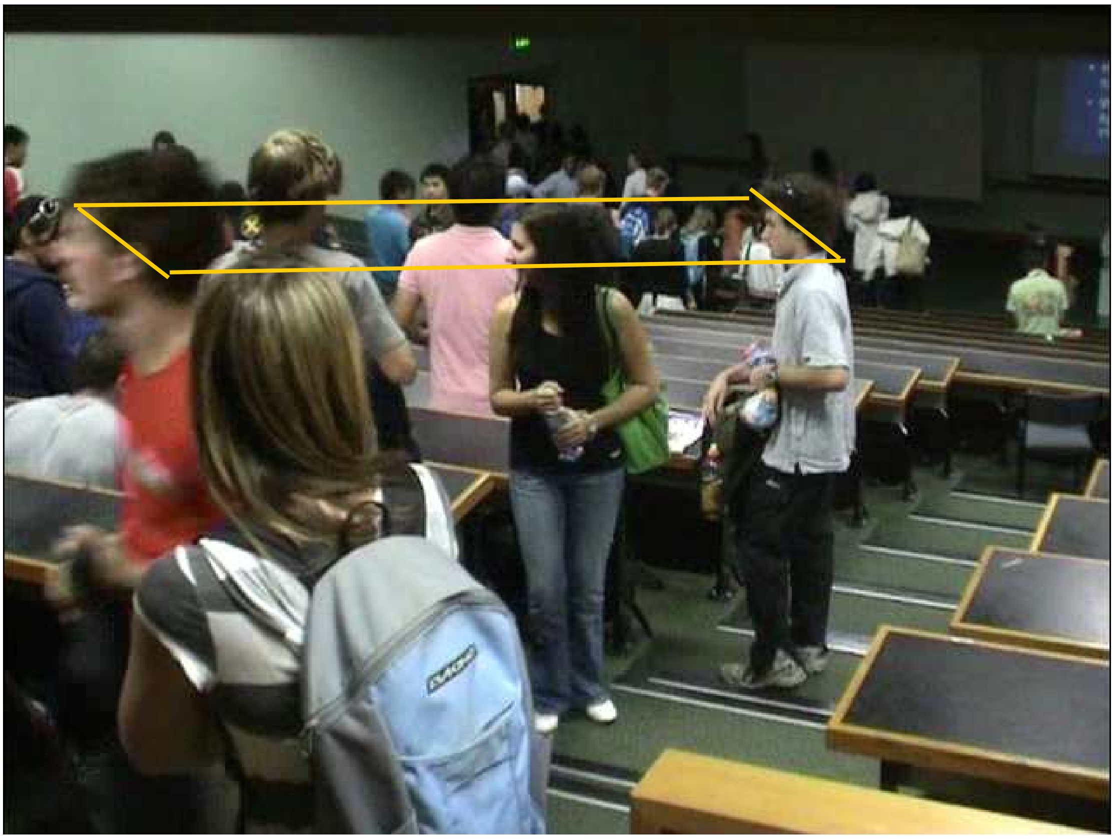

Figure B.16: Occupant density (C1 left aisle at 30s)

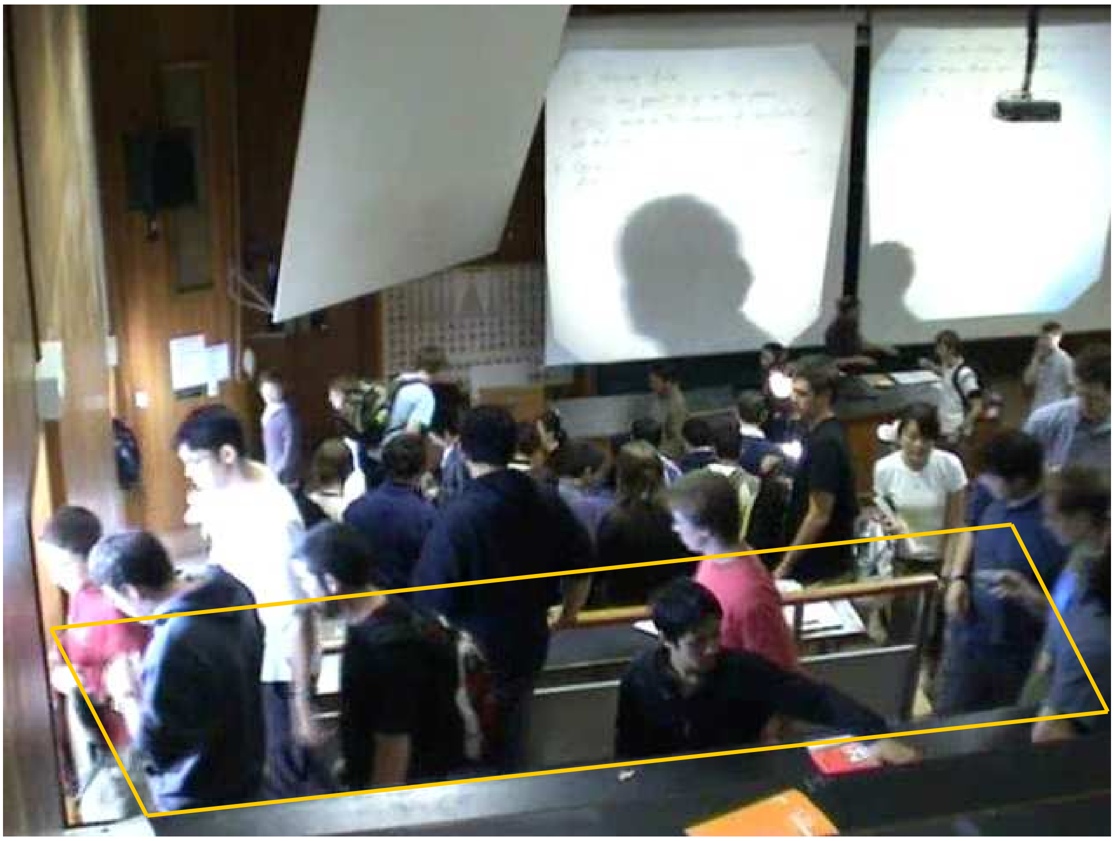

Figure B.17: Occupant density (S4 doorway at 10s)

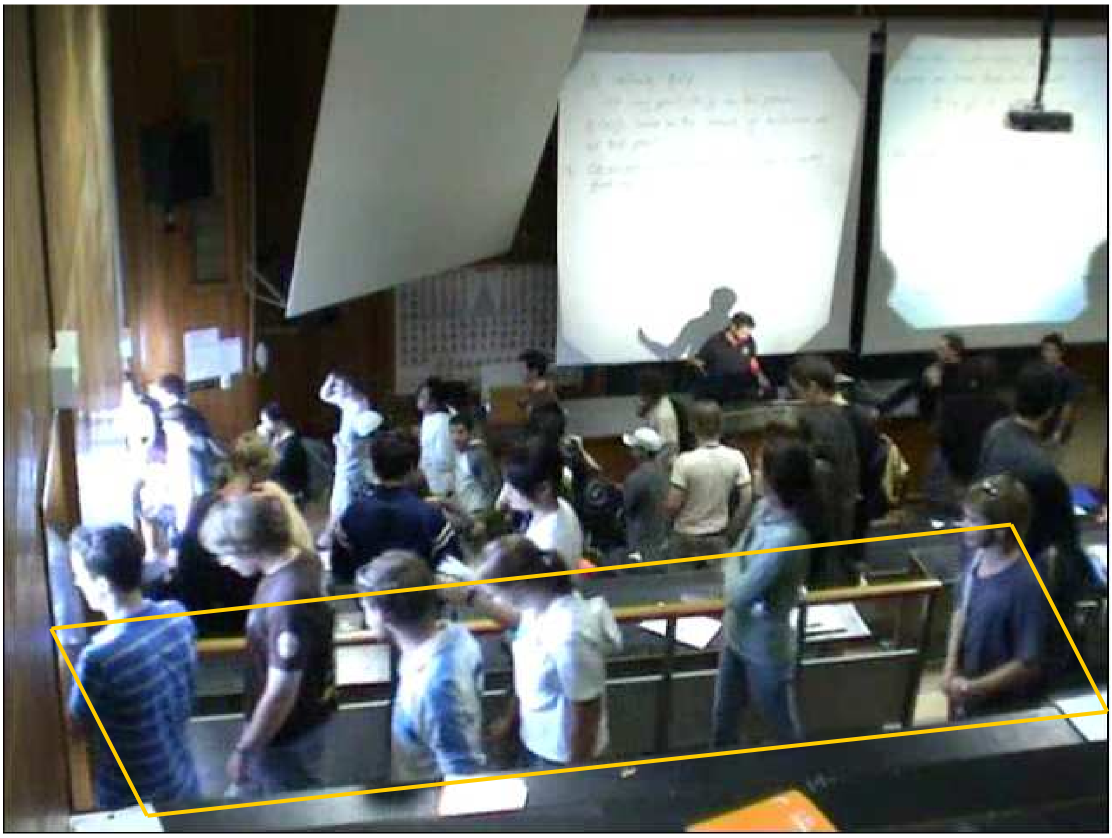

Figure B.18: Occupant density (S4 doorway at 20s)

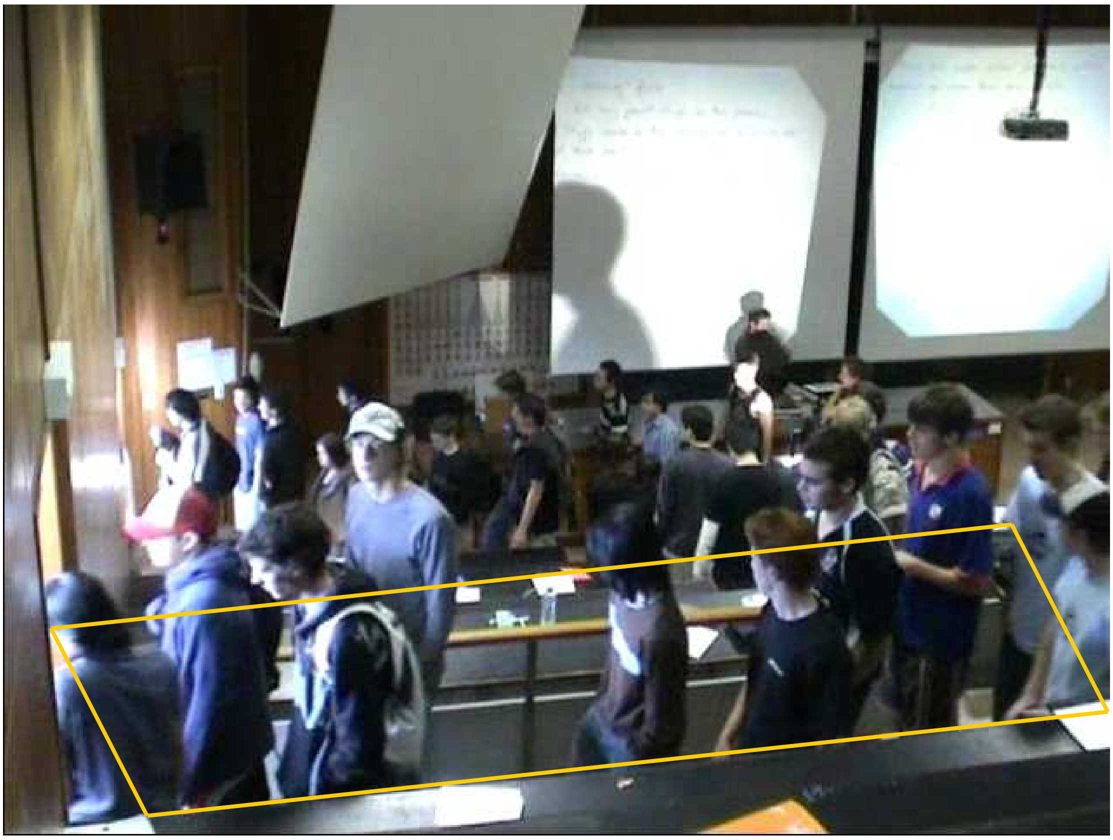

Figure B.19: Occupant density (S4 doorway at 30s)

Figure B.20: Occupant density (S4 doorway at 40s)

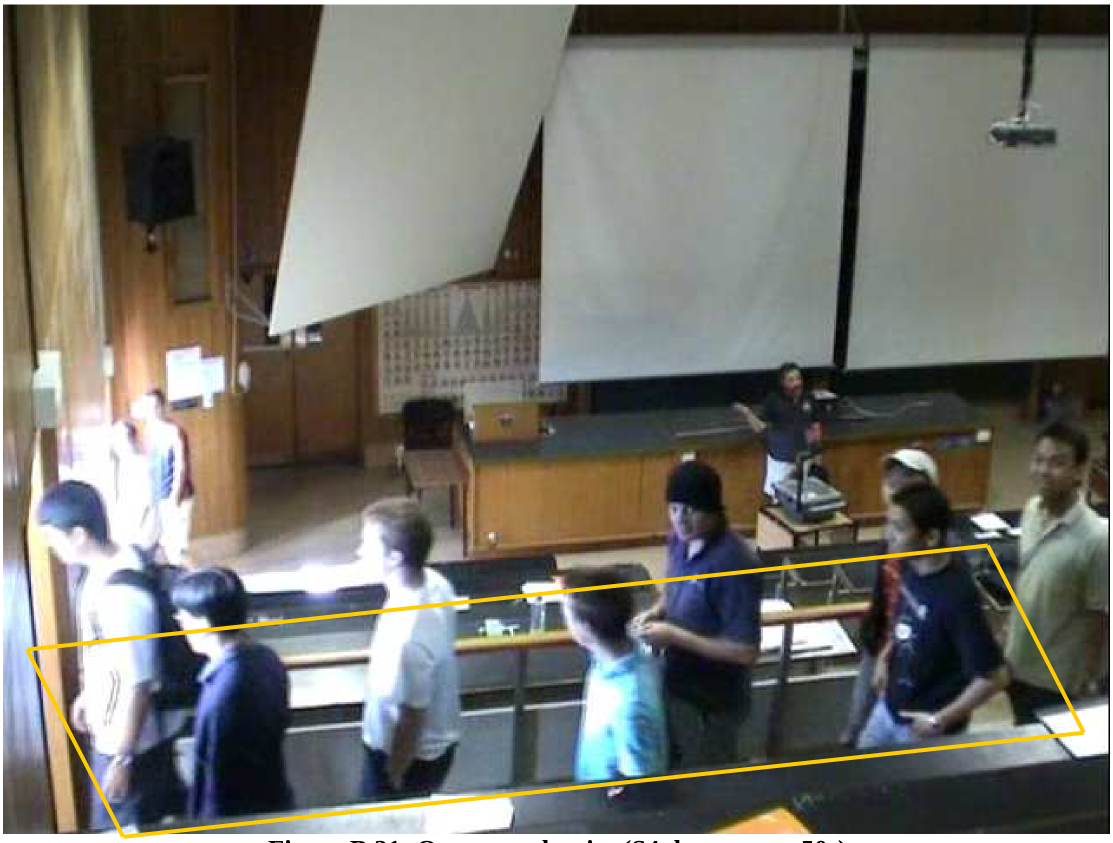

Figure B.21: Occupant density (S4 doorway at 50s)

APPENDIX C Travel Speed

Table C.1: Travel Speed

Location	Row	Travel distance (m)	Travel time (s)				Travel speed(m/s)			
			Person 1	Person 2	Person 3	Average	Person 1	Person 2	Person 3	Average
A1(right side)	10	6.8	49	48	41	46	0.14	0.14	0.17	0.15
	9	5.95	44	40	-	42	0.14	0.15		0.14
	8	5.1	18	33	31	27	0.28	0.15	0.16	0.20
	7	4.25	15	23	20	19	0.28	0.18	0.21	0.23
	6	3.4	18	16	15	16	0.19	0.21	0.23	0.21
	Average	5.1	29	32	27	30	0.21	0.17	0.19	**0.19**
A1(left side)	9	5.95	60	62	22	48	0.10	0.10	0.27	0.16
	8	5.1	43	44	43	43	0.12	0.12	0.12	0.12
	7	4.25	28	26	25	26	0.15	0.16	0.17	0.16
	6	3.4	24	25	12	20	0.14	0.14	0.28	0.19
	5	2.55	11	15	11	12	0.23	0.17	0.23	0.21
	Average	4.25	33	34	23	30	0.15	0.14	0.21	**0.17**
C1(right side)	9	6.8	13	10	25	16	0.52	0.68	0.27	0.27
	8	5.95	19	19	17	18	0.31	0.31	0.35	0.33
	7	5.1	12	11	17	13	0.43	0.46	0.30	0.40
	Average	5.95	16	15	20	16	0.37	0.39	0.31	**0.33**
C1(left side)	9	6.8	26	20	18	21	0.26	0.34	0.38	0.33
	8	5.95	10	20	16	18	0.60	0.30	0.37	0.33
	7	5.1	19	21	12	17	0.27	0.24	0.43	0.31
	Average	5.95	23	20	15	19	0.26	0.29	0.39	**0.32**

APPENDIX D Flow Rate

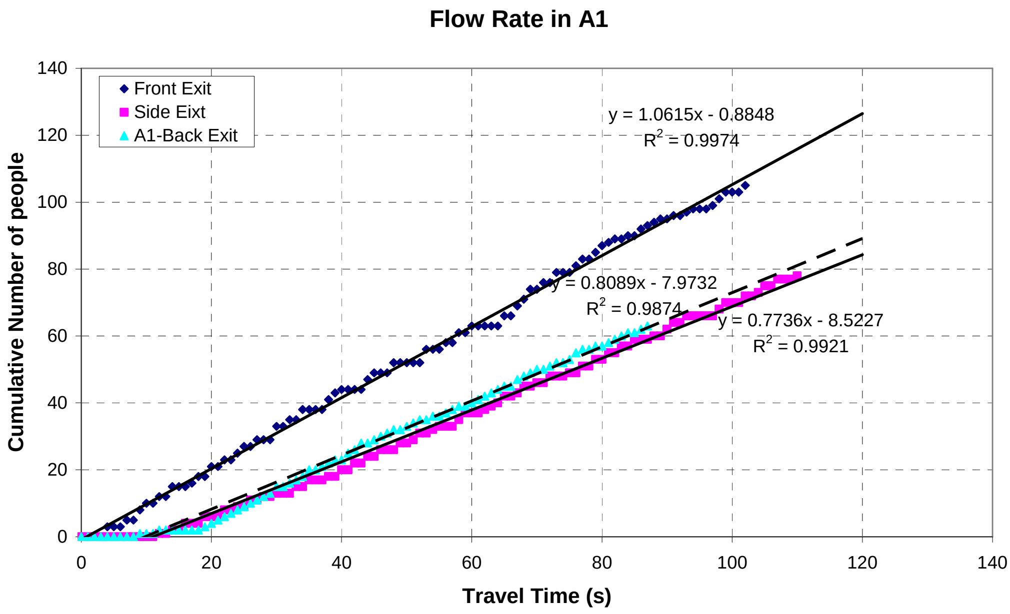

Figure D.1: Flow rate in A1

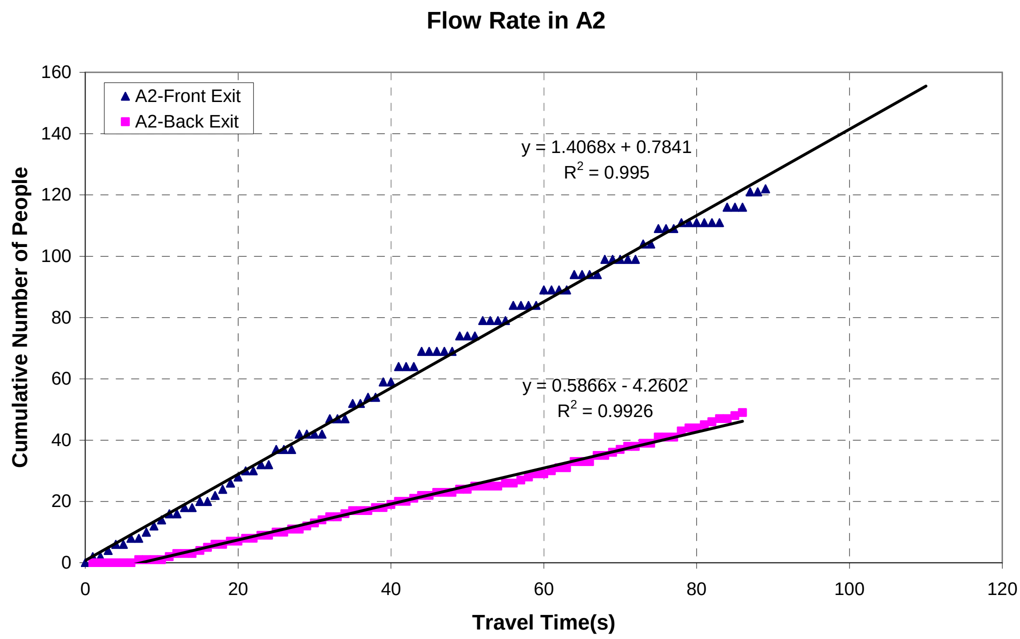

Figure D.2: Flow rate in A2

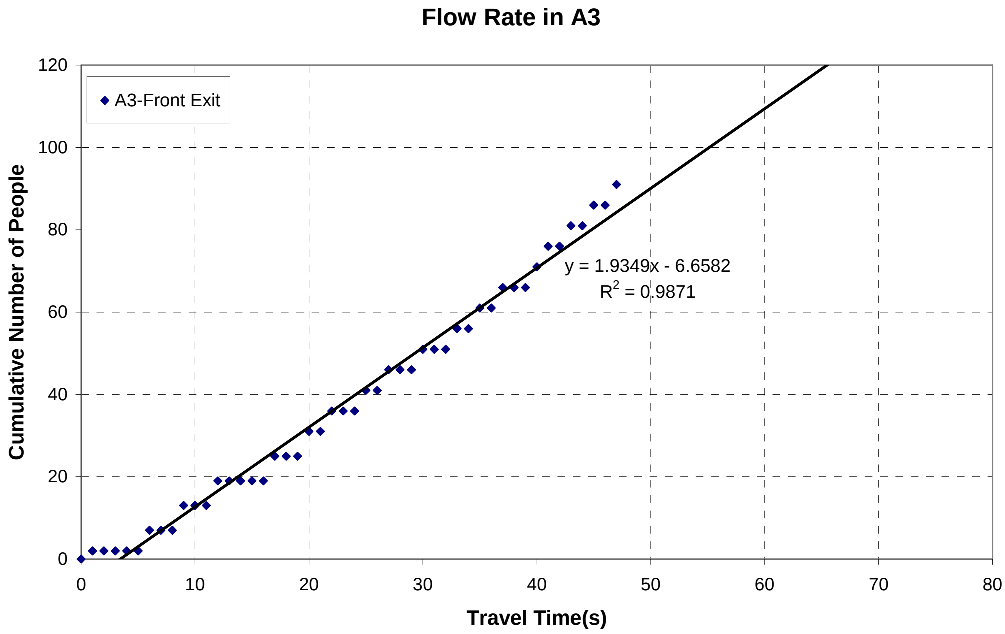

Figure D.3: Flow rate in A3

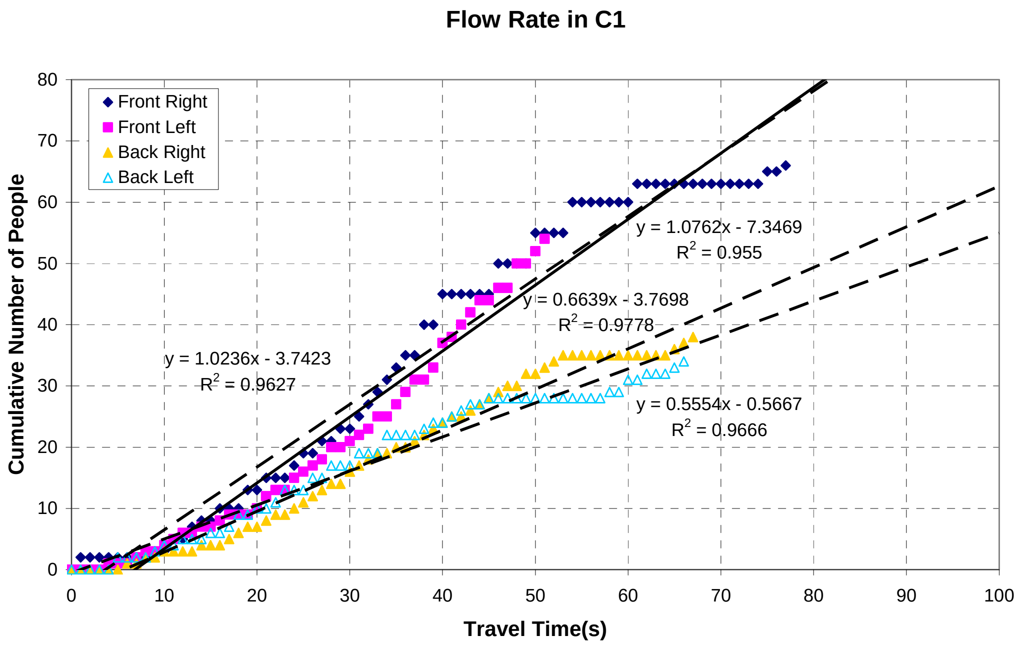

Figure D.4: Flow rate in C1

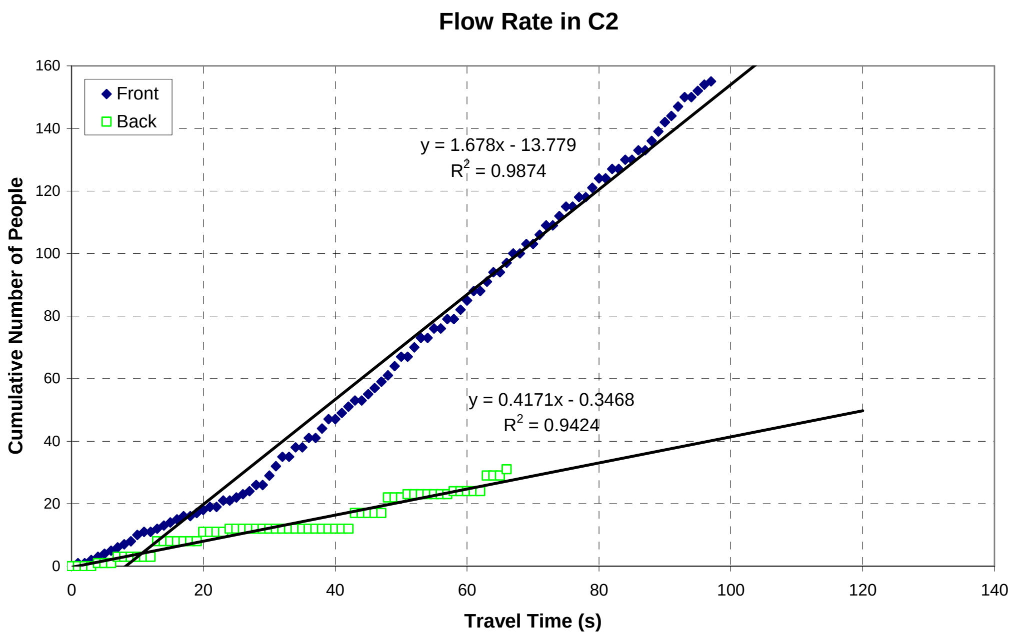

Figure D.5: Flow rate in C2

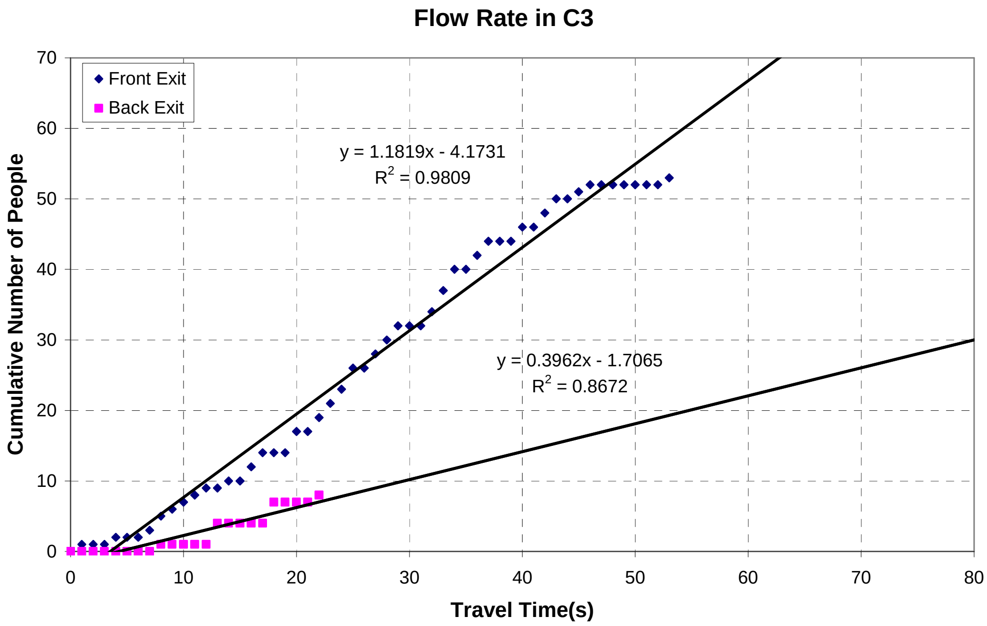

Figure D.6: Flow rate in C3

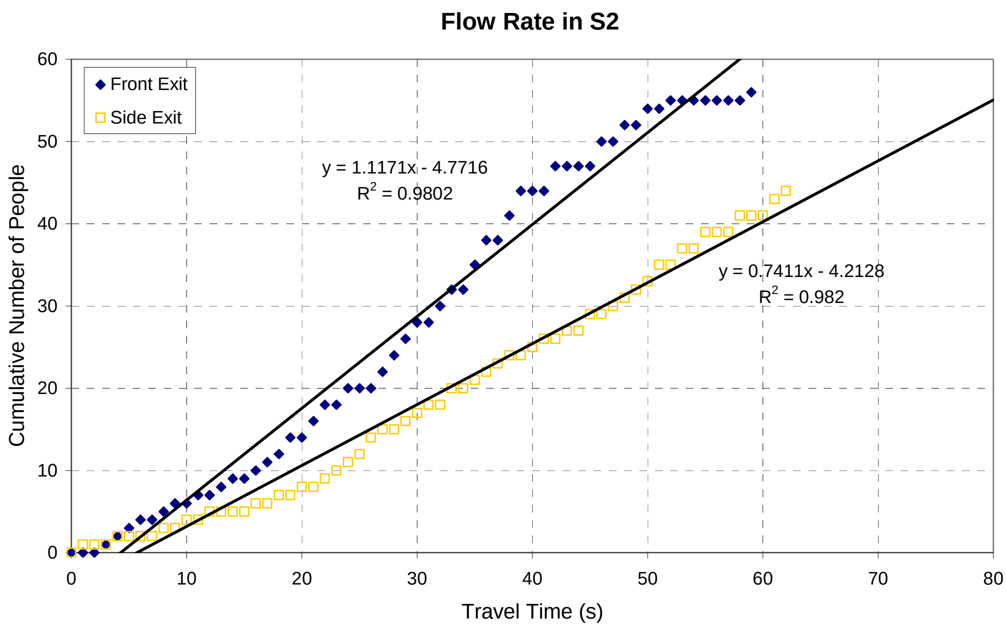

Figure D.7: Flow rate in S2

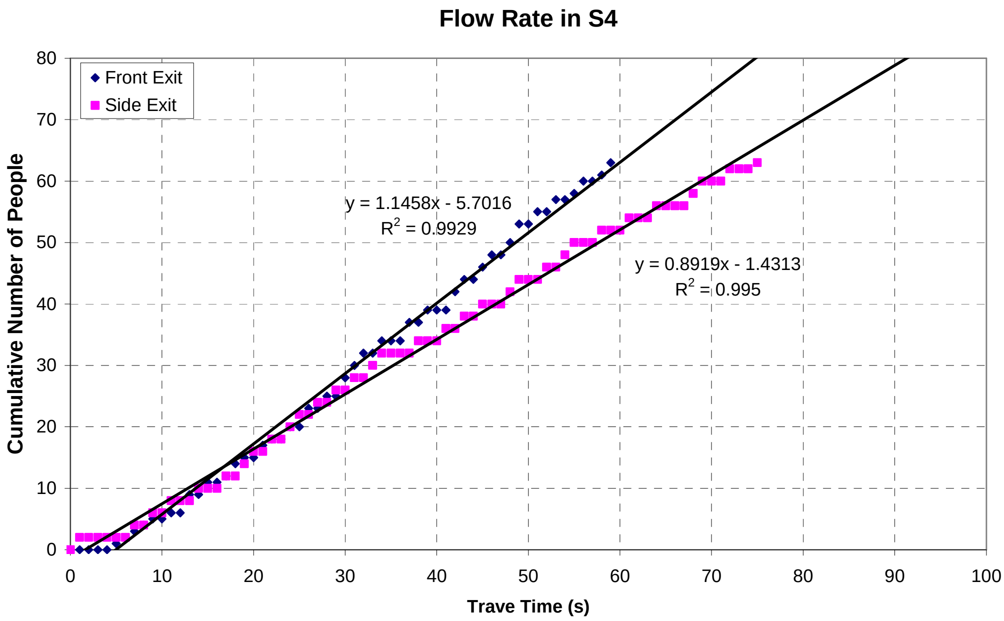

Figure D.8: Flow rate in S4

Table D.1: Value of flow rate and R^2 for each exit

Location	Flow Rate(ppl/m^2)	R^2
A1(Main)	1.06	0.9974
A1(side)	0.81	0.9921
A1(Back)	0.84	0.9874
A2(Front)	1.41	0.9950
A2(Back)	0.59	0.9926
A3(Front)	1.66	0.9871
C1(Front Right)	1.02	0.9772
C1(Front Left)	1.08	0.9550
C1(Back Right)	0.66	0.9778
C1(Back Left)	0.56	0.9666
C2(Front)	1.68	0.9874
C2(Back)	0.41	0.9424
C3(Front)	1.18	0.9809
C3 (Back)	0.4	0.8672
S2(Front)	1.12	0.9802
S2(Back)	0.74	0.9820
S4(Front)	1.15	0.9929
S4(Back)	0.89	0.9950
	Average	**0.9753**

APPENDIX E Calculation of Correlation Coefficient

To calculation the correlation coefficient, following steps are preformed (McEwen, 1995):

1) Calculate the arithmetic mean and standard deviation of both set of dependant and independent data.
2) Convert the values of both variables to **standard units**.

$$S\tan dard\ units = \frac{x_j - \bar{x}}{s}$$

Where

$\bar{x}$ = arithmetic mean

s = sample standard deviation

3) Take the product of the standard units for each pair
4) Sum up the results and divide by the number of points minus 1.

Table E.1: The results of Correlation Calculation

Correlation of travel time

Location	Travel Time (s)	Standard unit	Population	Standard unit	Product	Occupant Density(ppl/m^2)	Standard unit	Product	Aisle Width(m)	Standard unit	Product	Door Width(m)	Standard unit	Product
A1	100	1.41	246	1.60	2.27	0.77	0.39	0.55	1.2	-1.30	-1.84	3.2	1.05	1.49
A2	83	0.41	171	0.39	0.16	1.04	1.54	0.63	1.2	-1.30	-0.53	2.4	-0.40	-0.16
A3	66	-0.60	96	-0.83	0.50	0.80	0.53	-0.32	1.8	0.43	-0.26	2.4	-0.40	0.24
C1	74	-0.13	192	0.73	-0.09	0.51	-0.74	0.09	2	1.01	-0.13	3.75	2.05	-0.26
C2	99	1.35	186	0.63	0.85	0.73	0.22	0.30	2	1.01	1.37	2.25	-0.67	-0.91
C3	55	-1.25	61	-1.40	1.75	0.24	-1.89	2.36	2	1.01	-1.26	2.25	-0.67	0.84
S2	59	-1.01	100	-0.77	0.78	0.64	-0.16	0.16	1.5	-0.43	0.44	2.35	-0.49	0.49
S4	73	-0.19	126	-0.34	0.06	0.70	0.10	-0.02	1.5	-0.43	0.08	2.35	-0.49	0.09
Mean	76	-	147	-	-	0.68	-	-	1.65	-	-	2.62	-	-
Deviation	17	-	62	-	-	0.23	-	-	0.35	-	-	0.55	-	-
Correlation	**-**	**-**		**0.90**			**0.54**			**-0.30**			**0.26**	

Correlation of flow rate

Location	Flow Rate(ppl/s)	Standard unit	Population	Standard unit	Product	Occupant Density(ppl/m^2)	Standard unit	Product	Aisle Width(m)	Standard unit	Product	Door Width(m)	Standard unit	Product
A1	0.9	-0.45	246	1.60	-0.72	0.77	0.39	-0.18	1.2	-1.30	0.58	3.2	1.05	1.49
A2	1	-0.08	171	0.39	-0.03	1.04	1.54	-0.13	1.2	-1.30	0.11	2.4	-0.40	-0.16
A3	1.66	2.33	96	-0.83	-1.94	0.80	0.53	1.23	1.8	0.43	1.01	2.4	-0.40	0.24
C1	0.83	-0.70	192	0.73	-0.51	0.51	-0.74	0.52	2	1.01	-0.71	3.75	2.05	-0.26
C2	1.05	0.10	186	0.63	0.06	0.73	0.22	0.02	2	1.01	0.10	2.25	-0.67	-0.91
C3	0.79	-0.85	61	-1.40	1.19	0.24	-1.89	1.60	2	1.01	-0.86	2.25	-0.67	0.84
S2	0.93	-0.34	100	-0.77	0.26	0.64	-0.16	0.05	1.5	-0.43	0.15	2.35	-0.49	0.49
S4	1.02	-0.01	126	-0.34	0.00	0.70	0.10	0.00	1.5	-0.43	0.00	2.35	-0.49	0.09
Mean	1.02	-	147	-	-	0.68	-	-	1.65	-	-	2.62	-	-
Deviation	0.27	-	62	-	-	0.23	-	-	0.35	-	-	0.55	-	-
Correlation	**-**	**-**		**-0.24**			**0.45**			**-0.30**			**0.26**	

APPENDIX F Prediction of the New Relationship & Comparison with Other Methods

Table F.1: Prediction of Evacuation time using new relationship

Location	Number of people	Exit Choice %	Room Density (ppl/m^2)	Queuing Density (ppl/m^2)	Door Width (m)	Aisle Width (m)	Calculated travel speed(m/s)	Calculated Flow Rate(ppl/s)	Calculated Travel Time(s)	Experimental Travel Time(s)	Pre-movement Time (s)	Predicted Evacuation Time(s)	Experiment Result(s)	Error %
A1(Main)	105	42.7	0.77	2.11	1.65	1.2	0.40	1.01	104	97	14	118	114	3.51
A1(side)	78	31.7			1.65	1.2		1.01	77	82				
A1(Back)	63	25.6			0.75	1.2		0.63	100	100				
A2(Front)	122	71.3	1.04	3.08	1.65	1.8	0.30	1.54	79	83	18	97	101	3.87
A2(Back)	49	28.7			0.75	1.8		0.70	70	79				
A3(Front)	95	99.0	0.80	2.21	1.65	1.8	0.39	1.41	67	66	18	85	84	1.19
A3(Back)	1	1.0			0.75	1.8		n/a	n/a	n/a				
C1(Front Right)	66	34.4	0.51	1.25	1.5	2	0.59	1.10	60	76	22	91	96	5.21
C1(Front Left)	54	28.1			1.5	2		1.10	49	51				
C1(Back Right)	38	19.8			0.75	2		0.55	69	67				
C1(Back Left)	34	17.7			0.75	2		0.55	62	66				
C2(Front)	155	83.3	0.73	1.97	1.5	2	0.42	1.66	94	99	18	112	117	4.68
C2(Back)	31	16.7			0.75	2		0.62	50	70				
C3(Front)	53	86.9	0.24	0.48	1.5	2	1.20	0.87	61	55	18	79	73	9.59
C3(Back)	8	13.1			0.75	2		n/a	n/a	n/a				
S2(Front)	56	56.0	0.64	1.67	1.4	1.5	0.47	1.11	50	59	18	76	77	1.30
S2(Back)	44	44.0			0.95	1.5		0.75	58	58				
S4(Front)	63	50.0	0.70	1.87	1.4	1.5	0.44	1.14	55	59	18	99	91	8.79
S4(Back)	63	50.0			0.95	1.5		0.78	81	73				
													Average	**4.77**
Verification of the new relationship														
E17	27	100.0	0.66	1.73	0.75	0.6	0.46	0.60	45	28	0	45	28	60.59
Study 1(main)	31	55.4	0.62	1.60	0.8	0.65	0.49	0.51	61	127	47	108	181	40.41
Study 1(fire exit)	25	44.6			0.76	0.85		0.60	42	134				
Study 2(main)	40	63	0.7	1.87	0.8	0.65	0.44	0.53	75	71	17	92	88	4.93
Study 2(fire exit)	23	37			0.76	0.85		0.62	37	58				
Theatre	306	100	1.05	3.12	3	2.3	0.30	2.16	142	151	66	208	217	4.22

Note:
E17: the experiment was carried out in lecture room E17 in Engineering Building on campus. Occupants were informed to have an evacuation practice.
Study 1&2: the trial evacuation data extracted from Kimura and Sime (1989) and Sime (1992). The evacuation was not announced in Study 1 but in Study 2.
Theatre: the evacuation exercise extracted from Weckman, Lehtimaki and Mannikko, (1999). The evacuees were not noticed beforehand.

Table F.2: Comparison of prediction for new method and other available methods

	New Relationship			Fruin (1976)			Predtechenskii & Milinskii (1978)			Nelson & MacLennan (2002)			Holmberg (1997)		
Location	Travel speed (m/s)	Specific flow (ppl/m/s)	$T_{Evacuation}$ (s)	Travel speed (m/s)	Specific flow (ppl/m/s)	$T_{Evacuation}$ (s)	Travel speed (m/s)	Specific flow (ppl/m/s)	$T_{Evacuation}$ (s)	Travel speed (m/s)	Specific flow (ppl/m/s)	$T_{Evacuation}$ (s)	Specific flow (ppl/m/s)	$T_{Evacuation}$ (s)	Experiment Result (s)
A1(Main)	0.40	0.84	118	1.14	0.88	109	0.74	0.57	161	0.80	0.61	151	1.53	60	114
A1(side)													1.53		
A1(Back)													1.81		
A2(Front)	0.30	0.93	97	1.04	1.08	85	0.74	0.77	114	0.72	0.75	116	2.24	54	101
A2(Back)													1.81		
A3(Front)	0.39	0.85	85	1.13	0.91	81	0.73	0.59	116	0.79	0.63	109	2.24	44	84
A3(Back)													1.81		
C1(Front Right)	0.59	0.73	91	1.24	0.63	102	0.94	0.48	128	0.86	0.44	137	2.21	50	96
C1(Front Left)													2.21		
C1(Back Right)													1.81		
C1(Back Left)													1.81		
C2(Front)	0.42	0.83	112	1.16	0.85	140	0.76	0.55	204	0.81	0.59	194	2.21	65	117
C2(Back)													1.81		
C3(Front)	1.20	0.58	79	1.35	0.32	129	1.12	0.27	149	0.94	0.22	175	2.21	34	73
C3(Back)													1.81		
S2(Front)	0.47	0.79	76	1.19	0.76	79	0.82	0.52	106	0.83	0.53	105	2.18	41	77
S2(Back)													1.98		
S4(Front)	0.44	0.82	99	1.17	0.82	99	0.78	0.54	140	0.81	0.57	134	2.18	52	91
S4(Back)													1.98		
E17	0.46	0.80	45	1.18	0.78	46	0.80	0.53	74	0.82	0.54	47	1.81	20	28
Study 1(main)	0.49	0.78	108	1.20	0.74	99	0.84	0.52	130	0.84	0.52	100	1.38	75	181
Study 1(fire exit													1.82		
Study 2(main)	0.44	0.82	92	1.20	0.74	84	0.84	0.52	124	0.84	0.52	86	1.38	53	88
Study 2(fire exit													1.82		
Theatre	0.30	0.94	208	1.05	1.10	158	0.75	0.78	217	0.72	0.76	162	1.80	123	217
		Aveg. Error	14.6%		Aveg. Error	27.7%		Aveg. Error	63.0%		Aveg. Error	55.0%	Aveg. Error	54.7%	

APPENDIX G EvacuatioNZ Input

Scenario 1

A1

a) MAP file:


```
<EvacuatioNZ_Map version="1.01">
   <Description>A1 - Scenario 1</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>16</Length>
      <Width>20</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Main</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Side</Name>
      <Ref>4</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Main</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>1.65</Width>
      </ConnectionType>
              <ConnectionChoice type="Preferred"/>
   </Connection>
   <Connection exists="Yes">
      <Name>Route_Back</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>3</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>0.75</Width>
      </ConnectionType>
              <ConnectionChoice type="ExitSign"/>
   </Connection>
   <Connection exists="Yes">
      <Name>Route_Side</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>4</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>1.65</Width>
      </ConnectionType>
              <ConnectionChoice type="Preferred"/>
   </Connection>
</EvacuatioNZ_Map>
```


b) POPULATE file

```
<EvacuatioNZ_Map version="1.01">
<Definition>
        <People>246</People>
        <Log>No</Log>
        <Node type="single">1</Node>
        <PersonType>
            <Name>Normal1</Name>
            <Probability>74</Probability>
        </PersonType>
                   <PersonType>
            <Name>Normal2</Name>
            <Probability>26</Probability>
        </PersonType>
    </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
    <TimeMax>1200</TimeMax>
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
        <Simulation>simulation.xml</Simulation>
        <PostProcess>pp template.xml</PostProcess>
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```

f) EXIT BEHAVIOUR file

```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
        <ExitBehaviourType type="Preferred">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
          <ExitBehaviour name="Default2">
        <ExitBehaviourType type="ExitSign">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```

A2

a) MAP file:


```
<EvacuatioNZ_Map version="1.01">
   <Description>A2 - Scenario 1</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>15</Length>
      <Width>11</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Front</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Front</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>1.65</Width>
      </ConnectionType>
               <ConnectionChoice type="Preferred"/>
   </Connection>
   <Connection exists="Yes">
      <Name>Route_Back</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>3</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>0.75</Width>
      </ConnectionType>
               <ConnectionChoice type="ExitSign"/>
   </Connection>
</EvacuatioNZ_Map>
```


b) POPULATE file


```
<EvacuatioNZ_Map version="1.01">
   <Definition>
      <People>171</People>
      <Log>No</Log>
      <Node type="single">1</Node>
      <PersonType>
         <Name>Normal1</Name>
         <Probability>71</Probability>
      </PersonType>
               <PersonType>
         <Name>Normal2</Name>
         <Probability>29</Probability>
      </PersonType>
   </Definition>
</EvacuatioNZ_Populate>
```


c) SIMULATION file


```
<EvacuatioNZ_Simulation version="1.01">
   <TimeMax>1200</TimeMax>
```

```
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
        <Simulation>simulation.xml</Simulation>
        <PostProcess>pp template.xml</PostProcess>
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```

f) EXIT BEHAVIOUR file

```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
        <ExitBehaviourType type="Preferred">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
         <ExitBehaviour name="Default2">
        <ExitBehaviourType type="ExitSign">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```

<u>A3</u>

a) MAP file:

```
<EvacuatioNZ_Map version="1.01">
    <Description>A3 - Scenaro 1</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>12</Length>
        <Width>10</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
```

```
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.65</Width>
        </ConnectionType>
                   <ConnectionChoice type="Preferred"/>
    </Connection>
</EvacuatioNZ_Map>
```

b) POPULATE file

```
<EvacuatioNZ_Map version="1.01">
    <Definition>
        <People>96</People>
        <Log>No</Log>
        <Node type="single">1</Node>
        <PersonType>
            <Name>Normal1</Name>
            <Probability>100</Probability>
        </PersonType>
    </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
    <TimeMax>1200</TimeMax>
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
        <Simulation>simulation.xml</Simulation>
        <PostProcess>pp template.xml</PostProcess>
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
```

```
</EvacuatioNZ_PersonType>
```


f) EXIT BEHAVIOUR file


```
<EvacuatioNZ_ExitBehaviour version="1.01">
   <ExitBehaviour name="Default1">
      <ExitBehaviourType type="Preferred">
         <Probability>100</Probability>
      </ExitBehaviourType>
   </ExitBehaviour>
       <ExitBehaviour name="Default2">
      <ExitBehaviourType type="ExitSign">
         <Probability>100</Probability>
      </ExitBehaviourType>
   </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```


<u>C1</u>

a) MAP file:


```
<EvacuatioNZ_Map version="1.01">
   <Description>C1 - Scenario 1</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>20</Length>
      <Width>19</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Main1</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Main2</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back1</Name>
      <Ref>4</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back2</Name>
      <Ref>5</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Main1</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>1.65</Width>
      </ConnectionType>
              <ConnectionChoice type="Preferred"/>
   </Connection>
   <Connection exists="Yes">
      <Name>Route_Main2</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>3</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>1.65</Width>
      </ConnectionType>
              <ConnectionChoice type="Preferred"/>
```

```
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back1</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>4</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.75</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back2</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>5</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.75</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```

b) POPULATE file

```
<EvacuatioNZ_Map version="1.01">
    <Definition>
        <People>192</People>
        <Log>No</Log>
        <Node type="single">1</Node>
        <PersonType>
            <Name>Normal1</Name>
            <Probability>62</Probability>
        </PersonType>
                <PersonType>
            <Name>Normal2</Name>
            <Probability>38</Probability>
        </PersonType>
    </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
    <TimeMax>1200</TimeMax>
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
        <Simulation>simulation.xml</Simulation>
        <PostProcess>pp template.xml</PostProcess>
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```


f) EXIT BEHAVIOUR file


```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
        <ExitBehaviourType type="Preferred">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
           <ExitBehaviour name="Default2">
        <ExitBehaviourType type="ExitSign">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```


<u>C2</u>

a) MAP file:


```
<EvacuatioNZ_Map version="1.01">
    <Description>C2 - Scenario 1</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>17</Length>
        <Width>15</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.5</Width>
        </ConnectionType>
                  <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.75</Width>
        </ConnectionType>
```

```
                <ConnectionChoice type="ExitSign"/>
   </Connection>
</EvacuatioNZ_Map>
```

b) POPULATE file

```
<EvacuatioNZ_Map version="1.01">
   <Definition>
      <People>186</People>
      <Log>No</Log>
      <Node type="single">1</Node>
      <PersonType>
         <Name>Normal1</Name>
         <Probability>83</Probability>
      </PersonType>
                <PersonType>
         <Name>Normal2</Name>
         <Probability>17</Probability>
      </PersonType>
   </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
   <TimeMax>1200</TimeMax>
   <TimeStep>1</TimeStep>
   <MaxNodeDensity>2</MaxNodeDensity>
   <DoorFlow>Maclennan</DoorFlow>
   <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
   <Simulations>100</Simulations>
   <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
   <RandomStartPosition>Yes</RandomStartPosition>
   <Files>
      <Simulation>simulation.xml</Simulation>
      <PostProcess>pp template.xml</PostProcess>
      <Populate>populate.xml</Populate>
   </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
   <PersonType name="Normal1">
      <Speed>1.20</Speed>
      <ExitBehaviour>Default1</ExitBehaviour>
   </PersonType>
   <PersonType name="Normal2">
      <Speed>1.20</Speed>
      <ExitBehaviour>Default2</ExitBehaviour>
   </PersonType>
</EvacuatioNZ_PersonType>
```

f) EXIT BEHAVIOUR file

```
<EvacuatioNZ_ExitBehaviour version="1.01">
   <ExitBehaviour name="Default1">
      <ExitBehaviourType type="Preferred">
         <Probability>100</Probability>
      </ExitBehaviourType>
   </ExitBehaviour>
       <ExitBehaviour name="Default2">
```

```
        <ExitBehaviourType type="ExitSign">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```

<u>C3</u>

a) MAP file:

```
<EvacuatioNZ_Map version="1.01">
    <Description>C3 - Scenario 1</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>17</Length>
        <Width>15</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.5</Width>
        </ConnectionType>
                <ConnectionChoice type="Preferred"/>
    </Connection>
</EvacuatioNZ_Map>
```

b) POPULATE file

```
<EvacuatioNZ_Map version="1.01">
    <Definition>
        <People>61</People>
        <Log>No</Log>
        <Node type="single">1</Node>
        <PersonType>
            <Name>Normal1</Name>
            <Probability>100</Probability>
        </PersonType>
    </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
    <TimeMax>1200</TimeMax>
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
```

```
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
       <Simulation>simulation.xml</Simulation>
       <PostProcess>pp template.xml</PostProcess>
       <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```


e) PERSON TYPE file


```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
       <Speed>1.20</Speed>
       <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
       <Speed>1.20</Speed>
       <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```


f) EXIT BEHAVIOUR file


```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
       <ExitBehaviourType type="Preferred">
          <Probability>100</Probability>
       </ExitBehaviourType>
    </ExitBehaviour>
         <ExitBehaviour name="Default2">
       <ExitBehaviourType type="ExitSign">
          <Probability>100</Probability>
       </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```


S2

a) MAP file:


```
<EvacuatioNZ_Map version="1.01">
    <Description>S2 - Scenario 1</Description>
    <Node exists="Yes">
       <Name>Room_1</Name>
       <Ref>1</Ref>
       <Length>13</Length>
       <Width>12</Width>
    </Node>
    <Node exists="Yes">
       <Name>Exit_Front</Name>
       <Ref>2</Ref>
       <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
       <Name>Exit_Back</Name>
       <Ref>3</Ref>
       <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
       <Name>Route_Front</Name>
       <NodeRef>1</NodeRef>
       <NodeRef>2</NodeRef>
       <Length>0</Length>
       <ConnectionType type="Door">
          <Width>1.4</Width>
       </ConnectionType>
```

```
                <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.95</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```

b) POPULATE file

```
<EvacuatioNZ_Map version="1.01">
    <Definition>
        <People>100</People>
        <Log>No</Log>
        <Node type="single">1</Node>
        <PersonType>
            <Name>Normal1</Name>
            <Probability>56</Probability>
        </PersonType>
                <PersonType>
            <Name>Normal2</Name>
            <Probability>44</Probability>
        </PersonType>
    </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
    <TimeMax>1200</TimeMax>
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
        <Simulation>simulation.xml</Simulation>
        <PostProcess>pp template.xml</PostProcess>
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
```

```
    </PersonType>
</EvacuatioNZ_PersonType>
```

f) EXIT BEHAVIOUR file


```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
        <ExitBehaviourType type="Preferred">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
        <ExitBehaviour name="Default2">
        <ExitBehaviourType type="ExitSign">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```


S4

a) MAP file:


```
<EvacuatioNZ_Map version="1.01">
    <Description>S4 - Scenario 1</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>15</Length>
        <Width>12</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.4</Width>
        </ConnectionType>
                <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.95</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```


b) POPULATE file


```
<EvacuatioNZ_Map version="1.01">
    <Definition>
        <People>126</People>
```

```
        <Log>No</Log>
        <Node type="single">1</Node>
        <PersonType>
           <Name>Normal1</Name>
           <Probability>50</Probability>
        </PersonType>
                 <PersonType>
           <Name>Normal2</Name>
           <Probability>50</Probability>
        </PersonType>
    </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
    <TimeMax>1200</TimeMax>
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
        <Simulation>simulation.xml</Simulation>
        <PostProcess>pp template.xml</PostProcess>
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```

f) EXIT BEHAVIOUR file

```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
        <ExitBehaviourType type="Preferred">
           <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
          <ExitBehaviour name="Default2">
        <ExitBehaviourType type="ExitSign">
           <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```

E17

a) MAP file:

```
<EvacuatioNZ_Map version="1.01">
   <Description>E17 - Scenario 1</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>7.9</Length>
      <Width>5.2</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Front</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Front</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>0.75</Width>
      </ConnectionType>
               <ConnectionChoice type="Preferred"/>
   </Connection>

</EvacuatioNZ_Map>
```

b) POPULATE file

```
<EvacuatioNZ_Map version="1.01">
   <Definition>
      <People>27</People>
      <Log>No</Log>
      <Node type="single">1</Node>
      <PersonType>
         <Name>Normal1</Name>
         <Probability>100</Probability>
      </PersonType>
   </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
   <TimeMax>1200</TimeMax>
   <TimeStep>1</TimeStep>
   <MaxNodeDensity>2</MaxNodeDensity>
   <DoorFlow>Maclennan</DoorFlow>
   <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
   <Simulations>100</Simulations>
   <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
   <RandomStartPosition>Yes</RandomStartPosition>
   <Files>
      <Simulation>simulation.xml</Simulation>
      <PostProcess>pp template.xml</PostProcess>
```

```
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```

f) EXIT BEHAVIOUR file

```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
        <ExitBehaviourType type="Preferred">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
          <ExitBehaviour name="Default2">
        <ExitBehaviourType type="ExitSign">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```

<u>Study 1</u>

a) MAP file:

```
<EvacuatioNZ_Map version="1.01">
    <Description>Study1 - Scenario 1</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>10.5</Length>
        <Width>8.6</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.8</Width>
        </ConnectionType>
                  <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
```

```
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.76</Width>
        </ConnectionType>
                  <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```

b) POPULATE file

```
<EvacuatioNZ_Map version="1.01">
    <Definition>
        <People>56</People>
        <Log>No</Log>
        <Node type="single">1</Node>
        <PersonType>
            <Name>Normal1</Name>
            <Probability>55</Probability>
        </PersonType>
                  <PersonType>
            <Name>Normal2</Name>
            <Probability>45</Probability>
        </PersonType>
    </Definition>
</EvacuatioNZ_Populate>
```

c) SIMULATION file

```
<EvacuatioNZ_Simulation version="1.01">
    <TimeMax>1200</TimeMax>
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```

d) SCENARIO file

```
<EvacuatioNZ_Scenario version="1.01">
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
        <Simulation>simulation.xml</Simulation>
        <PostProcess>pp template.xml</PostProcess>
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```

f) EXIT BEHAVIOUR file

```
<EvacuatioNZ_ExitBehaviour version="1.01">
   <ExitBehaviour name="Default1">
      <ExitBehaviourType type="Preferred">
         <Probability>100</Probability>
      </ExitBehaviourType>
   </ExitBehaviour>
       <ExitBehaviour name="Default2">
      <ExitBehaviourType type="ExitSign">
         <Probability>100</Probability>
      </ExitBehaviourType>
   </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```


Study 2

a) MAP file:


```
<EvacuatioNZ_Map version="1.01">
   <Description>Study2 - Scenario 1</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>10.5</Length>
      <Width>8.6</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Front</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Front</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>0.8</Width>
      </ConnectionType>
               <ConnectionChoice type="Preferred"/>
   </Connection>
   <Connection exists="Yes">
      <Name>Route_Back</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>3</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>0.76</Width>
      </ConnectionType>
               <ConnectionChoice type="ExitSign"/>
   </Connection>
</EvacuatioNZ_Map>
```


b) POPULATE file


```
<EvacuatioNZ_Map version="1.01">
   <Definition>
      <People>63</People>
      <Log>No</Log>
      <Node type="single">1</Node>
      <PersonType>
         <Name>Normal1</Name>
```

```
            <Probability>63</Probability>
        </PersonType>
                   <PersonType>
            <Name>Normal2</Name>
            <Probability>37</Probability>
        </PersonType>
    </Definition>
</EvacuatioNZ_Populate>
```


c) SIMULATION file


```
<EvacuatioNZ_Simulation version="1.01">
    <TimeMax>1200</TimeMax>
    <TimeStep>1</TimeStep>
    <MaxNodeDensity>2</MaxNodeDensity>
    <DoorFlow>Maclennan</DoorFlow>
    <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```


d) SCENARIO file


```
<EvacuatioNZ_Scenario version="1.01">
    <Simulations>100</Simulations>
    <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
    <RandomStartPosition>Yes</RandomStartPosition>
    <Files>
        <Simulation>simulation.xml</Simulation>
        <PostProcess>pp template.xml</PostProcess>
        <Populate>populate.xml</Populate>
    </Files>
</EvacuatioNZ_Scenario>
```


e) PERSON TYPE file


```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```


f) EXIT BEHAVIOUR file


```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
        <ExitBehaviourType type="Preferred">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
          <ExitBehaviour name="Default2">
        <ExitBehaviourType type="ExitSign">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```

Theatre

a) MAP file:


```
<EvacuatioNZ_Map version="1.01">
   <Description>Theatre - Scenario 1</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>20</Length>
      <Width>14.5</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Front</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Front</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>3</Width>
      </ConnectionType>
               <ConnectionChoice type="Preferred"/>
   </Connection>
</EvacuatioNZ_Map>
```


b) POPULATE file


```
<EvacuatioNZ_Map version="1.01">
   <Definition>
      <People>306</People>
      <Log>No</Log>
      <Node type="single">1</Node>
      <PersonType>
         <Name>Normal1</Name>
         <Probability>100</Probability>
      </PersonType>
   </Definition>
</EvacuatioNZ_Populate>
```


c) SIMULATION file


```
<EvacuatioNZ_Simulation version="1.01">
   <TimeMax>1200</TimeMax>
   <TimeStep>1</TimeStep>
   <MaxNodeDensity>2</MaxNodeDensity>
   <DoorFlow>Maclennan</DoorFlow>
   <OccupantDensityModel
localOccupantDensity="2.0">mixed</OccupantDensityModel>
</EvacuatioNZ_Simulation>
```


d) SCENARIO file


```
<EvacuatioNZ_Scenario version="1.01">
   <Simulations>100</Simulations>
   <DumpEvacuationTimes>Yes</DumpEvacuationTimes>
   <RandomStartPosition>Yes</RandomStartPosition>
   <Files>
      <Simulation>simulation.xml</Simulation>
      <PostProcess>pp template.xml</PostProcess>
      <Populate>populate.xml</Populate>
```

```
    </Files>
</EvacuatioNZ_Scenario>
```

e) PERSON TYPE file

```
<EvacuatioNZ_PersonType version="1.01">
    <PersonType name="Normal1">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default1</ExitBehaviour>
    </PersonType>
    <PersonType name="Normal2">
        <Speed>1.20</Speed>
        <ExitBehaviour>Default2</ExitBehaviour>
    </PersonType>
</EvacuatioNZ_PersonType>
```

f) EXIT BEHAVIOUR file

```
<EvacuatioNZ_ExitBehaviour version="1.01">
    <ExitBehaviour name="Default1">
        <ExitBehaviourType type="Preferred">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
          <ExitBehaviour name="Default2">
        <ExitBehaviourType type="ExitSign">
            <Probability>100</Probability>
        </ExitBehaviourType>
    </ExitBehaviour>
</EvacuatioNZ_ExitBehaviour>
```

Scenario 2 (only MAP file)

A1

```
<EvacuatioNZ_Map version="1.01">
    <Description>A1 – Scenario 2</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>51.25</Length>
        <Width>2.4</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Main</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Side</Name>
        <Ref>4</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Main</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.65</Width>
        </ConnectionType>
```

```
            <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.75</Width>
        </ConnectionType>
            <ConnectionChoice type="ExitSign"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Side</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>4</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.65</Width>
        </ConnectionType>
            <ConnectionChoice type="Preferred"/>
    </Connection>
</EvacuatioNZ_Map>
```


A2


```
<EvacuatioNZ_Map version="1.01">
    <Description>A2 - Scenario 2</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>23.4</Length>
        <Width>3.6</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.65</Width>
        </ConnectionType>
            <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.75</Width>
        </ConnectionType>
            <ConnectionChoice type="ExitSign"/>
    </Connection>
```

```
</EvacuatioNZ_Map>
```


A3


```
<EvacuatioNZ_Map version="1.01">
   <Description>A3 - Scenaro 2</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>16.7</Length>
      <Width>3.6</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Front</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Front</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>1.65</Width>
      </ConnectionType>
               <ConnectionChoice type="Preferred"/>
   </Connection>
</EvacuatioNZ_Map>
```


C1


```
<EvacuatioNZ_Map version="1.01">
   <Description>C1 - Scenario 2</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>24</Length>
      <Width>4</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Main1</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Main2</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back1</Name>
      <Ref>4</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back2</Name>
      <Ref>5</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Main1</Name>
      <NodeRef>1</NodeRef>
```

```
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.65</Width>
        </ConnectionType>
                <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Main2</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.65</Width>
        </ConnectionType>
                <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back1</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>4</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.75</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back2</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>5</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.75</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```


C2


```
<EvacuatioNZ_Map version="1.01">
    <Description>C2 - Scenario 2</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>23.3</Length>
        <Width>4</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.5</Width>
```

```
        </ConnectionType>
                 <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.75</Width>
        </ConnectionType>
                 <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```


C3


```
<EvacuatioNZ_Map version="1.01">
    <Description>C3 - Scenario 2</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>7.6</Length>
        <Width>4</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.5</Width>
        </ConnectionType>
                 <ConnectionChoice type="Preferred"/>
    </Connection>
</EvacuatioNZ_Map>
```


S2


```
<EvacuatioNZ_Map version="1.01">
    <Description>S2 - Scenario 2</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>17.9</Length>
        <Width>2.8</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
```

```
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.4</Width>
        </ConnectionType>
                <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.95</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```


S4


```
<EvacuatioNZ_Map version="1.01">
    <Description>S4 - Scenario 2</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>22.5</Length>
        <Width>2.8</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>1.4</Width>
        </ConnectionType>
                <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.95</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```

E17


```
<EvacuatioNZ_Map version="1.01">
   <Description>E17 - Scenario 2</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>22.7</Length>
      <Width>0.6</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Front</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Front</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>0.75</Width>
      </ConnectionType>
               <ConnectionChoice type="Preferred"/>
   </Connection>
</EvacuatioNZ_Map>
```


Study 1


```
<EvacuatioNZ_Map version="1.01">
   <Description>Study1 - Scenario 2</Description>
   <Node exists="Yes">
      <Name>Room_1</Name>
      <Ref>1</Ref>
      <Length>18.7</Length>
      <Width>1.5</Width>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Front</Name>
      <Ref>2</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Node exists="Yes">
      <Name>Exit_Back</Name>
      <Ref>3</Ref>
      <NodeType>Safe</NodeType>
   </Node>
   <Connection exists="Yes">
      <Name>Route_Front</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>2</NodeRef>
      <Length>0</Length>
      <ConnectionType type="Door">
         <Width>0.8</Width>
      </ConnectionType>
               <ConnectionChoice type="Preferred"/>
   </Connection>
   <Connection exists="Yes">
      <Name>Route_Back</Name>
      <NodeRef>1</NodeRef>
      <NodeRef>3</NodeRef>
      <Length>0</Length>
```

```
        <ConnectionType type="Door">
            <Width>0.76</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```


Study 2


```
<EvacuatioNZ_Map version="1.01">
    <Description>Study2 - Scenario 2</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>21</Length>
        <Width>1.5</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.8</Width>
        </ConnectionType>
                <ConnectionChoice type="Preferred"/>
    </Connection>
    <Connection exists="Yes">
        <Name>Route_Back</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>3</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>0.76</Width>
        </ConnectionType>
                <ConnectionChoice type="ExitSign"/>
    </Connection>
</EvacuatioNZ_Map>
```


Theatre


```
<EvacuatioNZ_Map version="1.01">
    <Description>Theatre – Scenario 2</Description>
    <Node exists="Yes">
        <Name>Room_1</Name>
        <Ref>1</Ref>
        <Length>66.5</Length>
        <Width>2.3</Width>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Front</Name>
        <Ref>2</Ref>
        <NodeType>Safe</NodeType>
    </Node>
    <Node exists="Yes">
        <Name>Exit_Back</Name>
        <Ref>3</Ref>
```

```
        <NodeType>Safe</NodeType>
    </Node>
    <Connection exists="Yes">
        <Name>Route_Front</Name>
        <NodeRef>1</NodeRef>
        <NodeRef>2</NodeRef>
        <Length>0</Length>
        <ConnectionType type="Door">
            <Width>3</Width>
        </ConnectionType>
                   <ConnectionChoice type="Preferred"/>
    </Connection>
</EvacuatioNZ_Map>
```

APPENDIX H Prediction of EvacuatioNZ

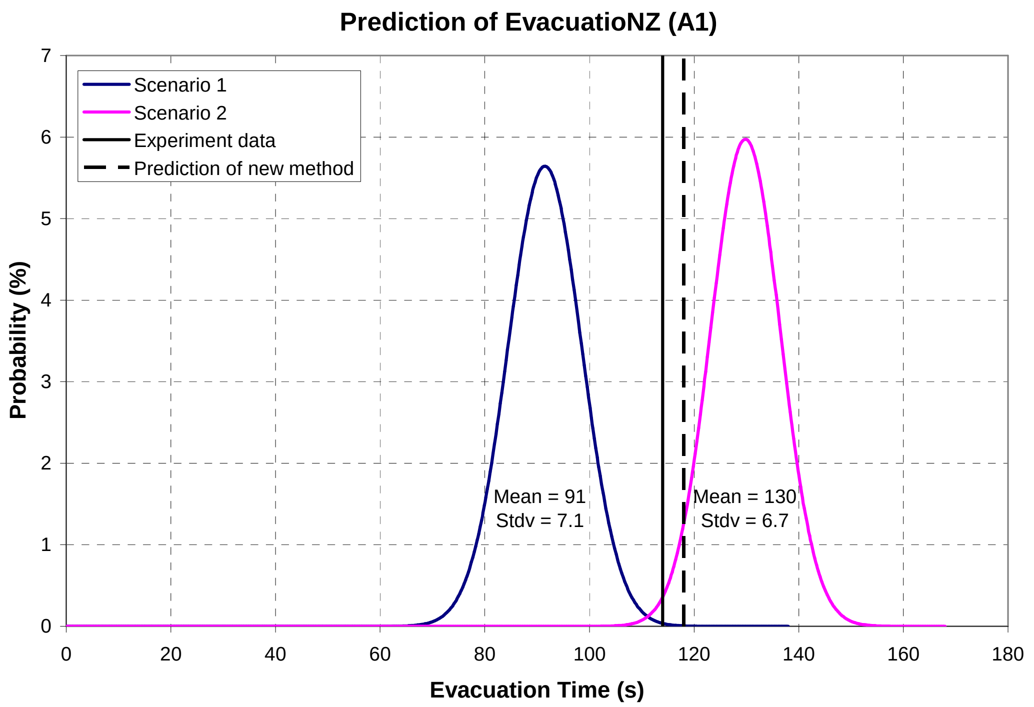

Figure H.1: Prediction of EvacuatioNZ (A1)

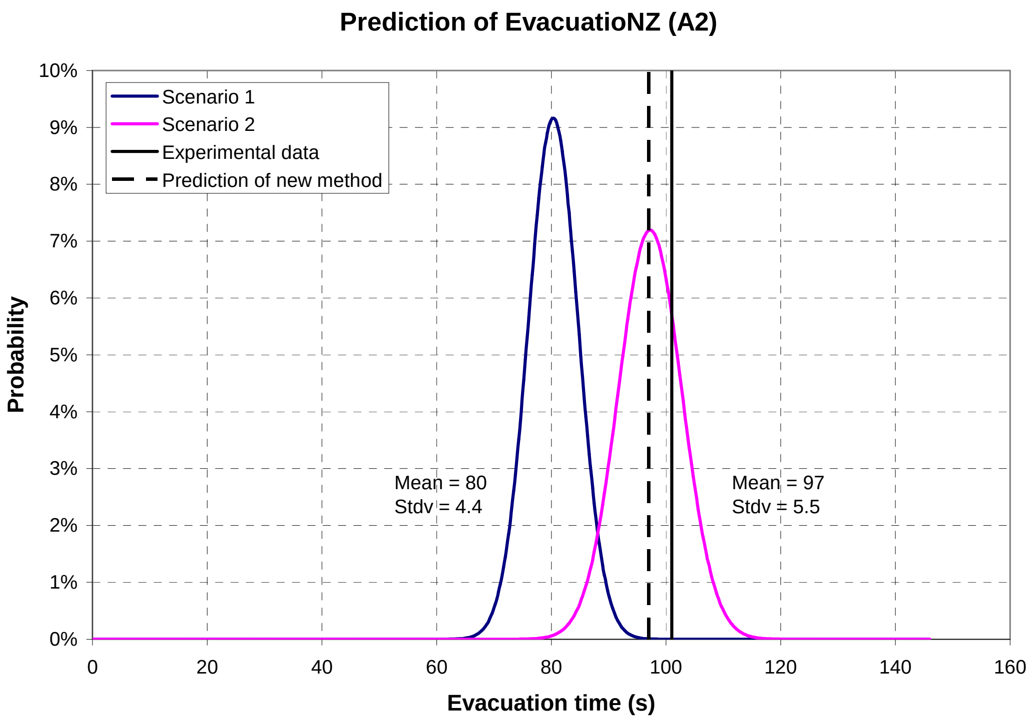

Figure H.2: Prediction of EvacuatioNZ (A2)

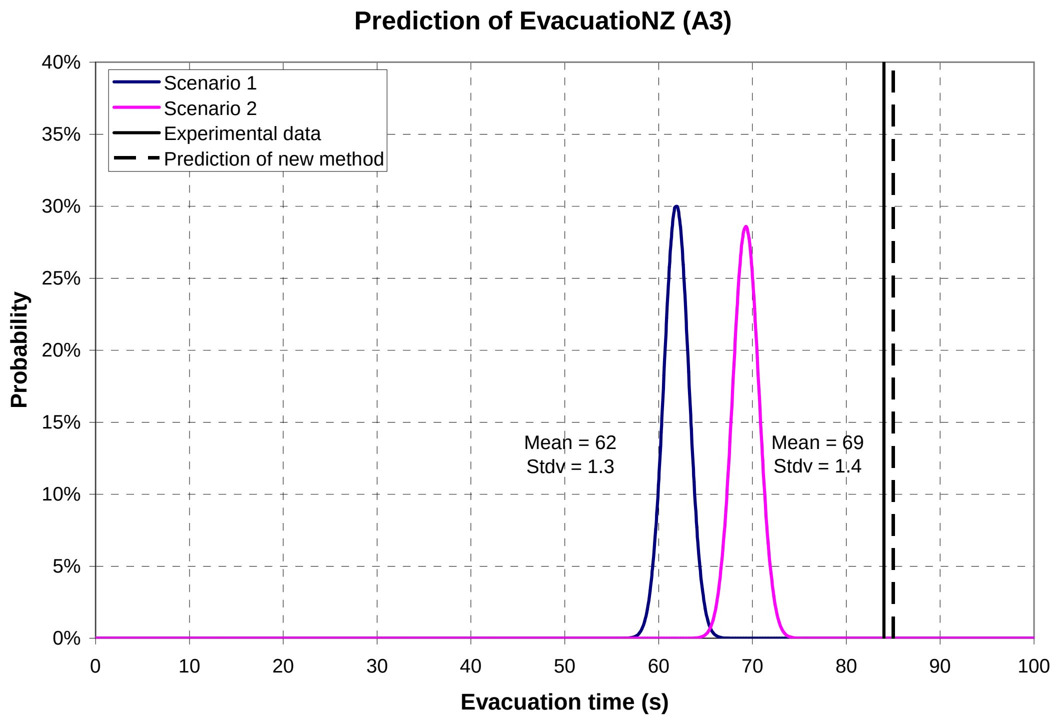

Figure H.3: Prediction of EvacuatioNZ (A3)

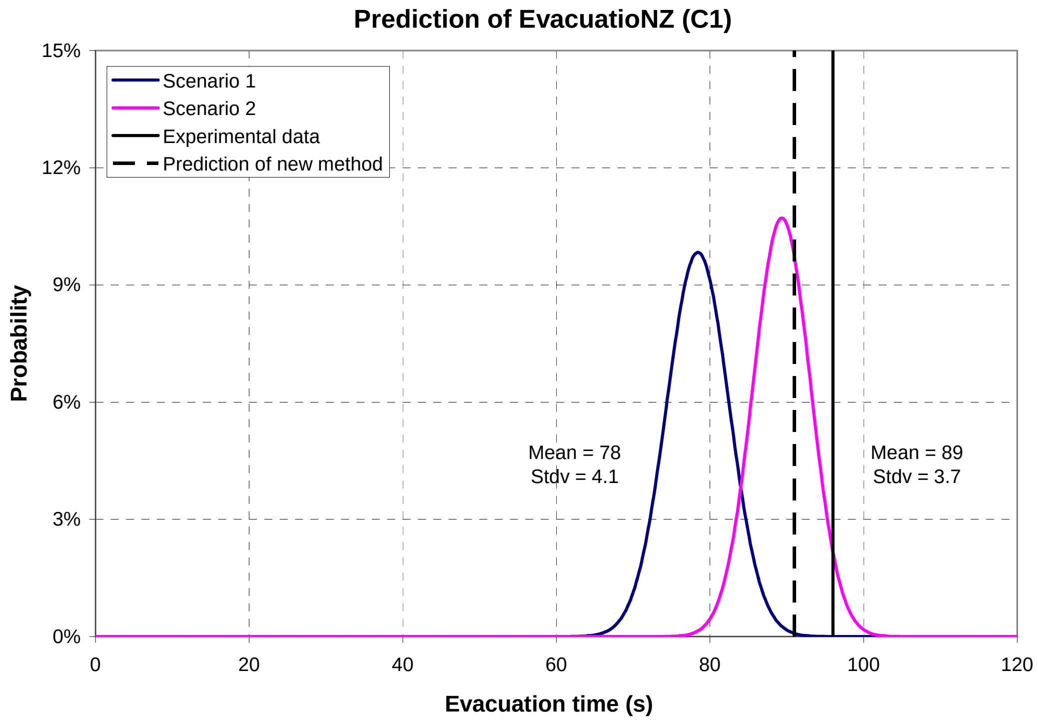

Figure H.4: Prediction of EvacuatioNZ (C1)

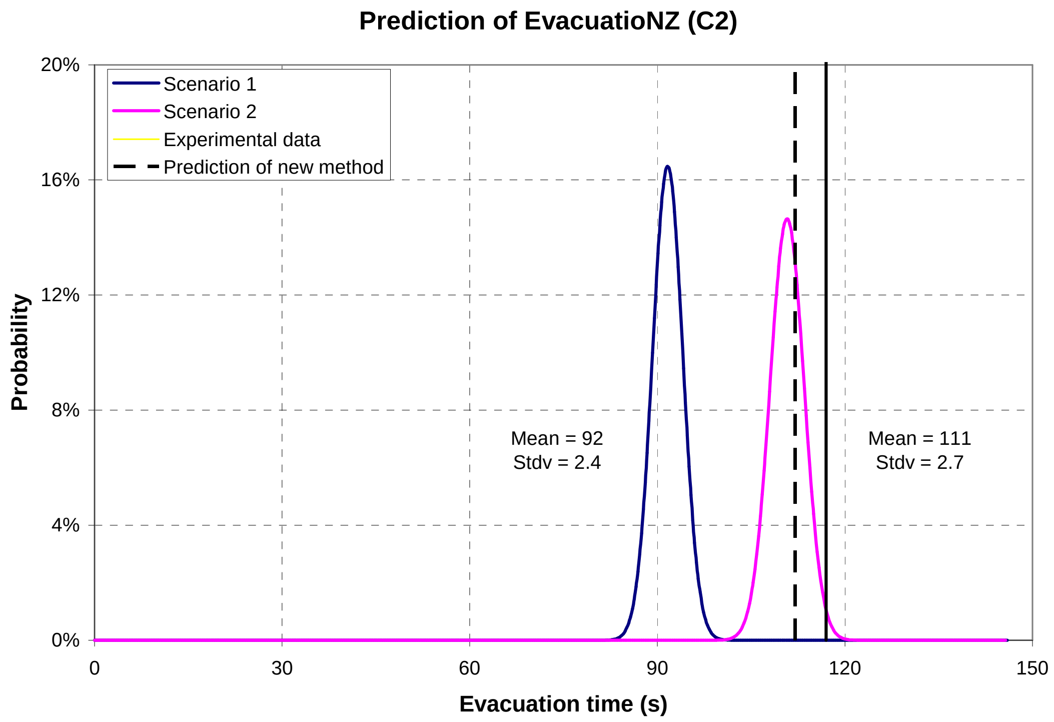

Figure H.5: Prediction of EvacuatioNZ (C2)

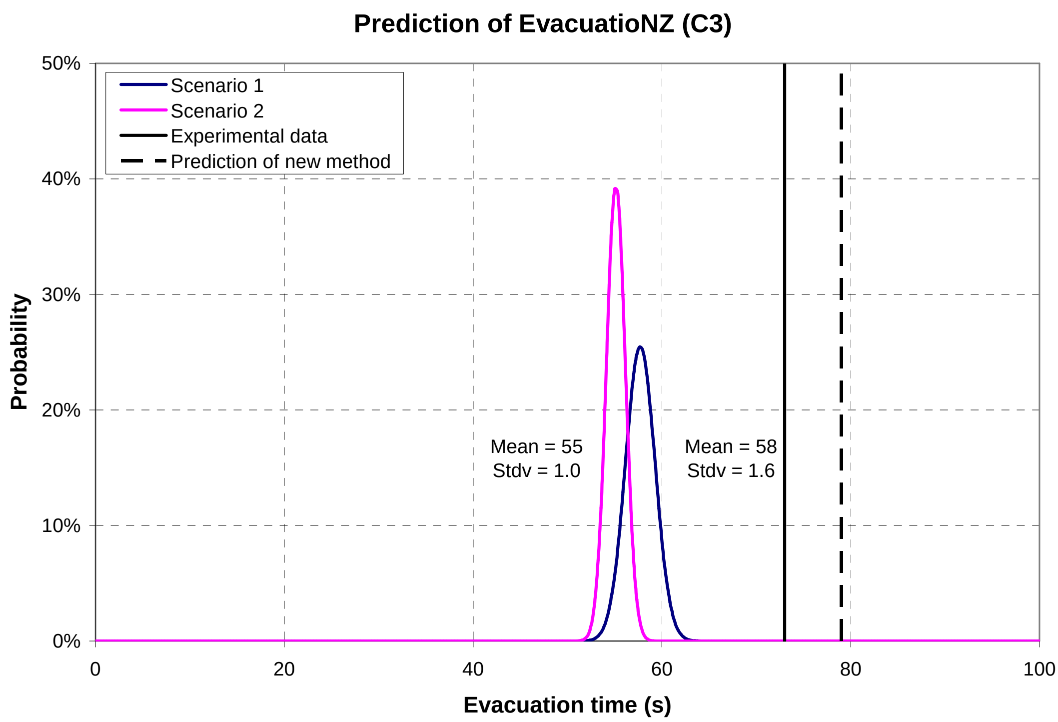

Figure H.6: Prediction of EvacuatioNZ (C3)

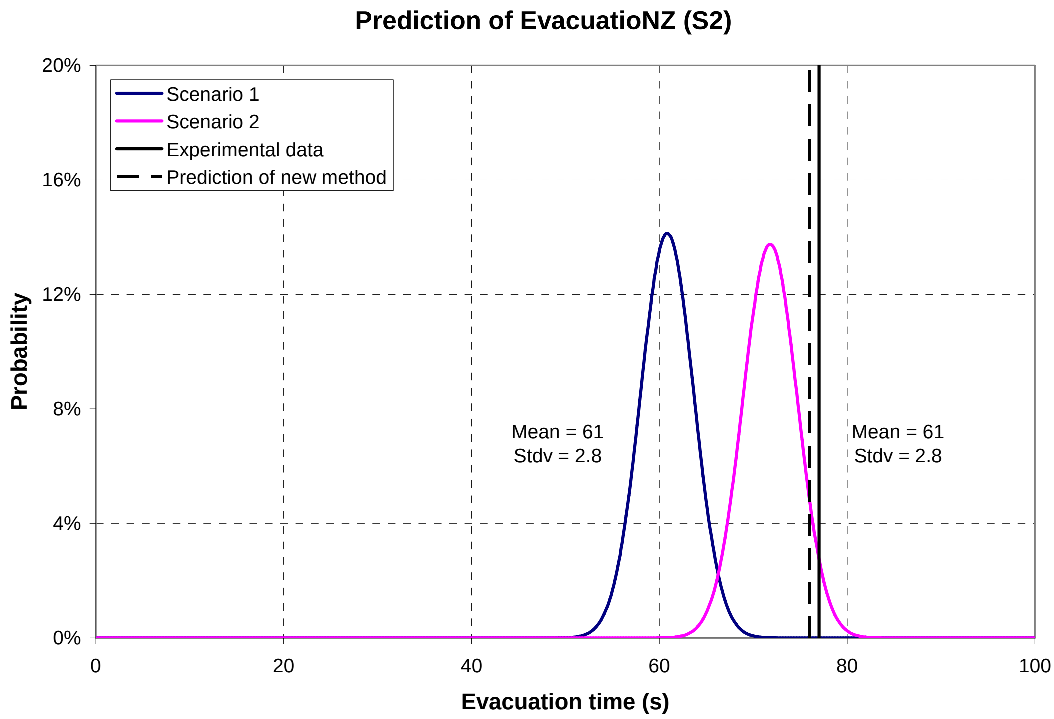

Figure H.7: Prediction of EvacuatioNZ (S2)

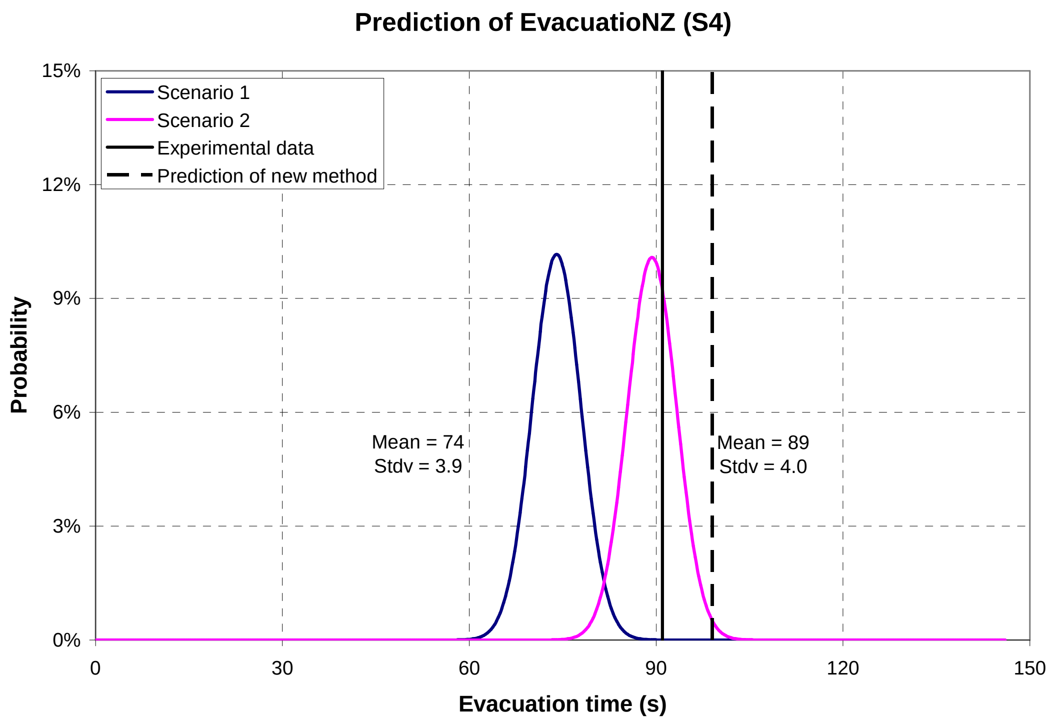

Figure H.8: Prediction of EvacuatioNZ (S4)

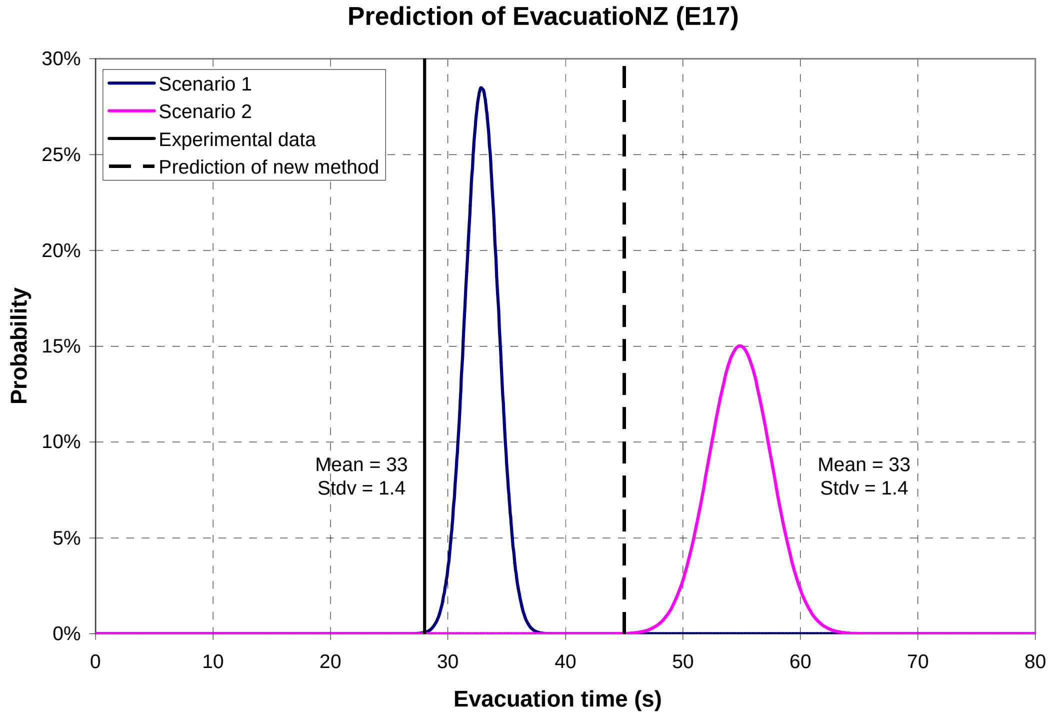

Figure H.9: Prediction of EvacuatioNZ (E17)

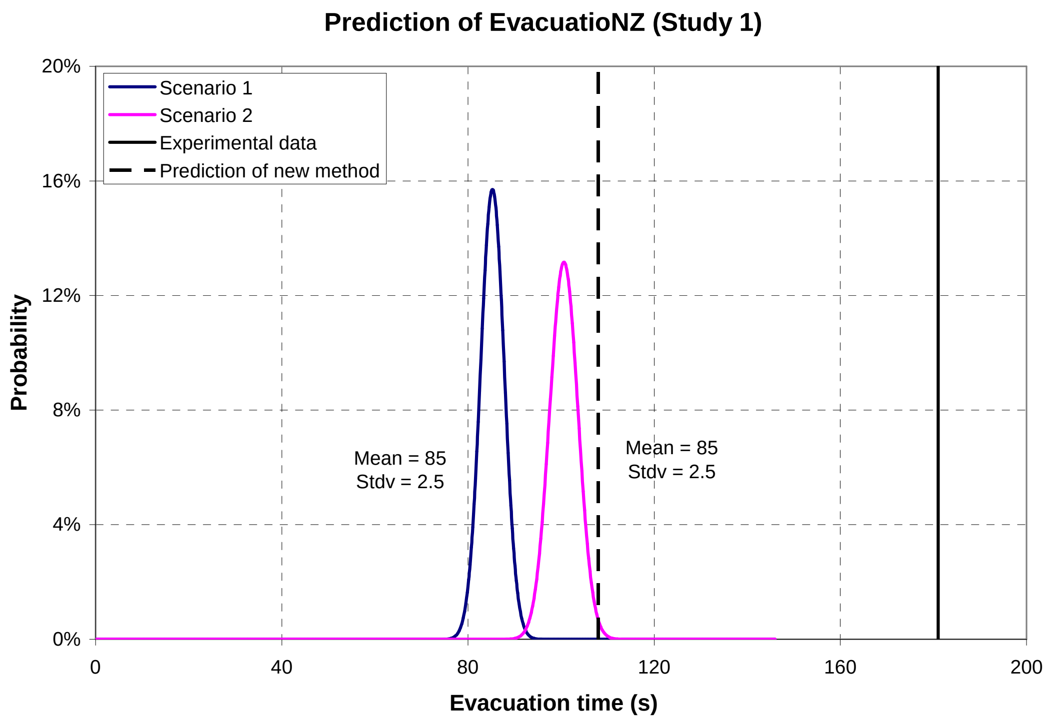

Figure H.10: Prediction of EvacuatioNZ (Study 1)

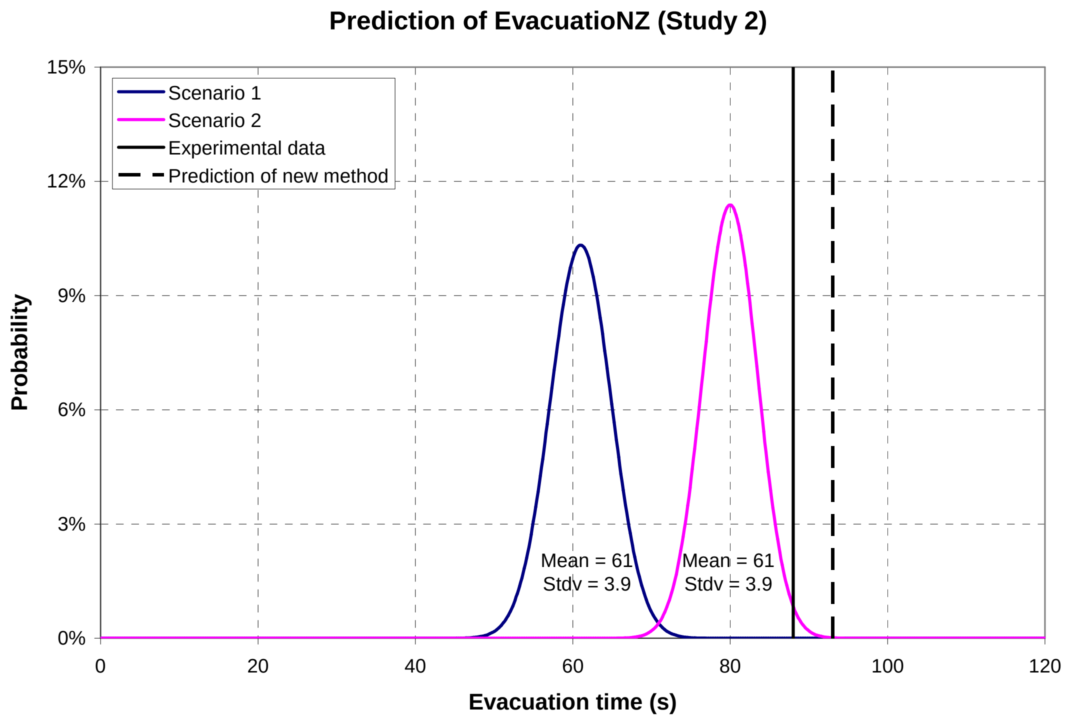

Figure H.11: Prediction of EvacuatioNZ (Study 2)

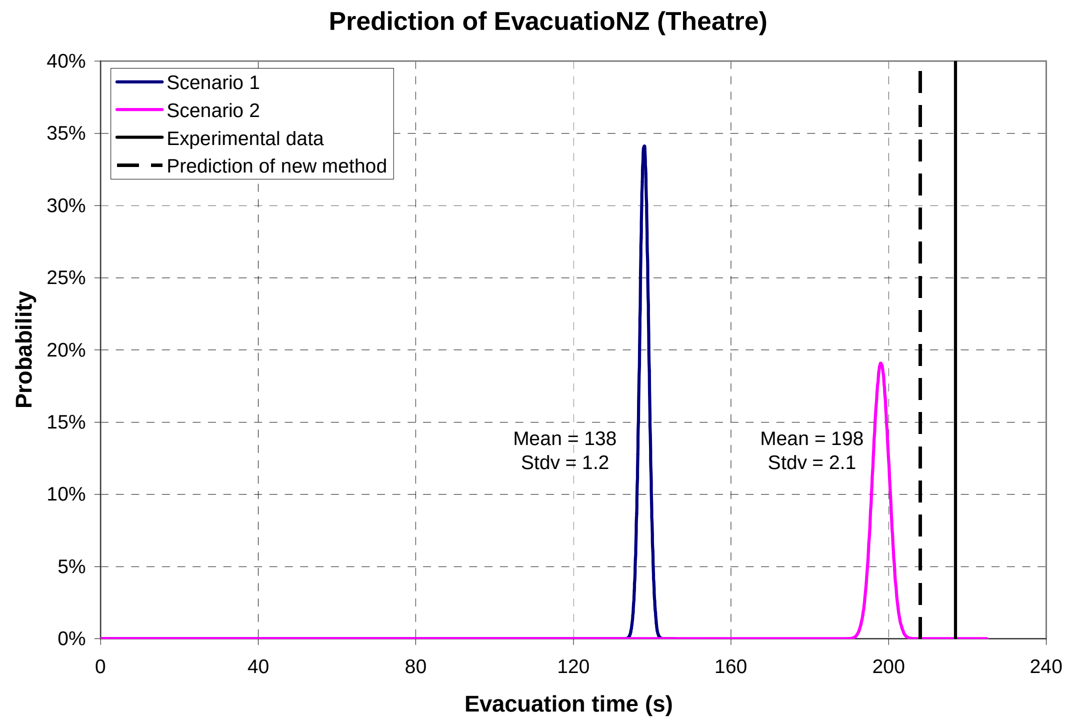

Figure H.12: Prediction of EvacuatioNZ (Theatre)

Table H.1: Comparison with new method and experiment data

Room	Prediction of Scenario 1		Prediction of Scenario 2		Prediction of new method	Experiment Data
	Mean	Stdv	Mean	Stdv		
A-1	91	7.1	130	6.7	118	114
A-2	80	4.4	97	5.5	97	101
A-3	62	1.3	69	1.4	85	84
C-1	78	4.1	89	3.7	91	96
C-2	92	2.4	111	2.7	112	117
C-3	58	1.6	55	1.0	79	73
S-2	61	2.8	72	2.9	76	77
S-4	74	3.9	89	4.0	99	91
E17	33	1.4	55	2.7	45	28
Study 1	85	2.5	101	3.0	108	181
Study 2	61	3.9	80	3.5	96	88
Theatre	138	1.2	198	2.1	208	217